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U S DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE		ATTORNEY'S DOCKET NUMBER
TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371		1454.1082/RAG 09/937766
INTERNATIONAL APPLICATION NO. PCT/DE00/00699	INTERNATIONAL FILING DATE 6 March 2000	PRIORITY DATE CLAIMED 31 March 1999

TITLE OF INVENTION
METHOD, USE OF SAID METHOD AND RECEIVER SYSTEM FOR RECEIVING MULTI-CARRIER SIGNALS PRESENTING SEVERAL FREQUENCY-DISCRETE SUBCARRIERS

APPLICANT(S) FOR DO/EO/US
Wolfgang ZIRWAS

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. [X] This is a FIRST submission of items concerning a filing under 35 U.S.C. 371.
2. [X] This is an express request to immediately begin national examination procedures (35 U.S.C. 371(f)).
3. [X] The US has been elected by the expiration of 19 months from the priority date (PCT Article 31).
4. [X] A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   a. [X] is transmitted herewith (required only if not transmitted by the International Bureau).
   b. [ ] has been transmitted by the International Bureau.
   c. [ ] is not required, as the application was filed in the United States Receiving Office (RO/US).
5. [X] A translation of the International Application into English (35 U.S.C. 371(c)(2)).
6. [ ] Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
   a. [ ] are transmitted herewith (required only if not transmitted by the International Bureau).
   b. [ ] have been transmitted by the International Bureau.
   c. [ ] is not required, as the application was filed in the United States Receiving Office (RO/US)
7. [ ] A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
8. [X] An oath or declaration of the inventor (35 U.S.C. 371(c)(4)).
9. [ ] A translation of the Annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 10-15 below concern document(s) or information included:

10. [X] An Information Disclosure Statement Under 37 CFR 1.97 and 1.98.
11. [X] An assignment document for recording.
    Please mail the recorded assignment document to:
    a. [X] the person whose signature, name & address appears at the bottom of this document.
    b. [ ] the following:
12. [X] A preliminary amendment.
13. [X] A substitute specification
14. [ ] A change of power of attorney and/or address letter.
15. [ ] Other items or information:

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[X] The U.S. National Fee (35 U.S.C. 371(c)(1)) and other fees as follows:

CLAIMS	(1) FOR	(2) NUMBER FILED	(3) NUMBER EXTRA	(4) RATE	(5) CALCULATIONS
	TOTAL CLAIMS	15 -20=	0	x $ 0.00	0.00
	INDEPENDENT CLAIMS	3 -3=	0	x $ 80.00	0.00
	MULTIPLE DEPENDENT CLAIM(S) (if applicable)			+$270.00	0.00
	BASIC NATIONAL FEE (37 CFR 1.492(a)(1)-(4): [ ] Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO ....$1,000 [X] International preliminary examination fee (37 C.F.R. 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO.. ....$ 890 [ ] International preliminary examination fee (37 C.F.R. 1.482) not paid to USPTO but international search fee (37 C.F.R. 1.445(a)(2) paid to USPTO...................$ 710 [ ] International preliminary examination fee paid to USPTO (37 CFR 1.482) but all claims did not satisfy provision of PCT Article 33(1)-(4).............$ 690 [ ] International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(2) to (4) ....$ 100				890.00
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	Reduction by 1/2 for filing by small entity, if applicable. Affidavit must be filed also. (Note 37 CFR 1.9, 1.27, 1.28.)				
			SUBTOTAL		890.00
	Processing fee of $130 for furnishing the English Translation later than [ ] 20 [ ] 30 mos. from the earliest claimed priority date (37 CFR 1.482(f)).				
			TOTAL NATIONAL FEE		0.00
	Fee for recording the enclosed assignment (37 CFR 1.21(h)).				+ 40.00
			TOTAL FEES ENCLOSED		930.00

a. [X] A check in the amount of $ 930.00 to cover the above fees is enclosed.

b. [ ] Please charge my Deposit Account No. 19-3935 in the Amount of $ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. [X] The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 19-3935. A duplicate copy of this sheet is enclosed.

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DATE

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09/937766
JC05 Rec'd PCT/PTO 01 OCT 2001

Docket No.: 1454.1082/RAG

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re the Application of:

Wolfgang ZIRWAS

Serial No. Group Art Unit: (unassigned)

Confirmation No.

Filed: (concurrently) Examiner: (unassigned)

For: METHOD AND SYSTEM FOR RECEIVING MULTI-CARRIER SIGNALS PRESENTING SEVERAL FREQUENCY-DISCRETE SUBCARRIERS (as amended)

PRELIMINARY AMENDMENT

Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

Before examination of the above-identified application, please amend the application as follows:

IN THE TITLE:

Please DELETE "METHOD, USE OF SAID" and change "A RECEIVING ARRANGEMENT" to --SYSTEM--.

IN THE SPECIFICATION:

Please REPLACE the pending specification with the Substitute Specification attached hereto.

IN THE ABSTRACT:

Please REPLACE the originally filed Abstract with the enclosed Substitute Abstract

IN THE CLAIMS:

Please CANCEL claims 1-15 without prejudice or disclaimer of any of the subject matter claimed therein and ADD new claims in accordance with the following:

16. (NEW) A method for receiving a multicarrier signal transmitted via a transmission medium subjecting each frequency-discrete subcarrier of the multicarrier signal to subcarrier-

specific disturbances caused by adjacent subcarriers in the frequency domain, the multicarrier signal having a number of frequency-discrete subcarriers and carrying inserted information converted by a multicarrier method to frequency-discrete modulation-specific modulation symbols, said method comprising:

superimposing on each frequency-discrete subcarrier of the multicarrier signal predetermined test disturbances to produce a deliberately disturbed multicarrier signal;

comparing disturbed modulation symbols in the deliberately disturbed multicarrier signal with undisturbed, modulation-specific modulation symbols, to derive subcarrier-specific error information;

deriving correction information representing the subcarrier-specific disturbances as a function of the predetermined test disturbances and the subcarrier-specific error information; and

correcting the frequency-discrete subcarriers of the multicarrier signal based on the correction information.

17. (NEW) The method as claimed in claim 16, wherein a number of different test disturbances are provided with each frequency-discrete subcarrier that is subjected to a test disturbance being disturbed by at least one of constant and frequency-dependent disturbance information.

18. (NEW) The method as claimed in claim 17,

further comprising establishing differently defined reference disturbance information items,

wherein said superimposing comprises

deriving from the multicarrier signal frequency-discrete received symbols representing the frequency-discrete subcarriers,

subjecting, for each reference disturbance information item, each of the frequency-discrete received symbols in adjacent subcarriers which are adjacent to at least some of the subcarriers in the frequency domain, to disturbances from the reference disturbance information item to produce disturbed symbols, and

superimposing the disturbed symbols in the adjacent subcarriers as the predetermined test disturbances on the received symbol to produce deliberately disturbed symbols,

wherein said comparing compares each deliberately disturbed symbol with a closest modulation-specific modulation symbol to form the subcarrier-specific error information, and

wherein said deriving comprises

forming disturbance-information-specific sum error information from the subcarrier-specific error information, and

deriving the correction information from the differently defined reference disturbance information items and the disturbance-information-specific sum error information items.

19. (NEW) The method as claimed in claim 18, further comprising:

at least one of delaying and temporarily storing the frequency-discrete received symbols derived from the multicarrier signal until the correction information has been established;

correcting the frequency-discrete received symbols, after said at least one of delaying and temporarily storing, by the determined correction information to produce corrected symbols; and

superimposing the corrected symbols on the frequency-discrete received symbols.

20. (NEW) The method as claimed in claim 18, wherein said deriving further comprises

establishing a correction function using the differently defined reference disturbance information items and the disturbance-information-specific sum error information items; and

calculating the correction information using the correction function.

21. (NEW) The method as claimed in claim 20,

wherein four differently defined reference disturbance information items are provided, and are used to derive four disturbance-information-specific sum error information items; and

wherein said calculating is performed by

$$ici_{opt} = \left(\frac{s\varepsilon 4 - \frac{(s\varepsilon 1 + s\varepsilon 3)}{2}}{2(s\varepsilon 1 - s\varepsilon 3)} \right) \bullet (ici1 - ici3) + \frac{ici4}{2}$$

where

sε1...4 represents the four disturbance-information-specific sum error information items, and

ici1...4 represents the four differently defined reference disturbance information items.

22. (NEW) The method as claimed in claim 18,

further comprising repeating said establishing, superimposing, comparing and deriving to determine the correction information iteratively until a minimum value of the disturbance-information-specific sum error information is determined.

23. (NEW) The method as claimed in claim 18, further comprising correcting each deliberately disturbed symbol by equalization as a function of frequency-selective transmission characteristics of the transmission medium before said comparing with the closest modulation-specific modulation symbol.

24. (NEW) The method as claimed in claim 18, further comprising, after said superimposing, comparing, deriving and correcting of the adjacent subcarriers:

subjecting the frequency-discrete received symbols of distant subcarriers, each arranged further away from at least some of the subcarriers in the frequency domain, to disturbances from the differently defined reference disturbance information items to produce distant disturbed symbols;

superimposing the distant disturbed symbols as deliberate test disturbances on each received symbol to produce additionally disturbed subcarriers; and

repeating said comparing, deriving and correcting using the additionally disturbed subcarriers.

25. (NEW) The method as claimed in claim 17, wherein error identification information is inserted into the multicarrier signal prior to transmission

wherein said method further comprises:

demodulating corrected symbols resulting from said correcting of the frequency-discrete subcarriers to produce demodulated symbols,

identifying errors in the demodulated symbols using the error identification information to produce identified erroneous symbols;

correcting identified erroneous symbols to produce corrected erroneous symbols;

determining additional correction information using the corrected erroneous symbols; and

repeating said comparing, deriving and correcting of the frequency-discrete subcarriers using the additional correction information.

26. (NEW) The method as claimed in claim 16, wherein the multicarrier signal is generated by one of an Orthogonal Frequency Division Multiplexing transmission method and a transmission method based on discrete multiple tones.

27. (NEW) The method as claimed in claim 16, wherein the transmission medium is one of a wireless radio channel, a cable-based transmission channel and a wire-based transmission channel.

28. (NEW) The method as claimed in claim 27, wherein the transmission medium includes power supply lines.

29. (NEW) A method for receiving a multicarrier signal transmitted via a transmission medium subjecting each frequency-discrete subcarrier of the multicarrier signal to subcarrier-specific disturbances caused by adjacent subcarriers in the frequency domain, the multicarrier signal having a number of frequency-discrete subcarriers and carrying inserted information converted by a multicarrier method to frequency-discrete modulation-specific modulation symbols, said method comprising:

demodulating the multicarrier signal to produce a demodulated multicarrier signal;

identifying and correcting errors in the demodulated multicarrier signal using an error handling routine; and

when a predetermined number of errors that cannot be corrected are found,

superimposing on each frequency-discrete subcarrier of the multicarrier signal predetermined test disturbances to produce a deliberately disturbed multicarrier signal;

comparing disturbed modulation symbols in the deliberately disturbed multicarrier signal with undisturbed, modulation-specific modulation symbols, to derive subcarrier-specific error information;

deriving correction information representing the subcarrier-specific disturbances as a function of the predetermined test disturbances and the subcarrier-specific error information; and

correcting the frequency-discrete subcarriers of the multicarrier signal based on the correction information.

30. (NEW) A system for receiving a multicarrier signal transmitted via a transmission medium subjecting each frequency-discrete subcarrier of the multicarrier signal to subcarrier-specific disturbances caused by adjacent subcarriers in the frequency domain, the multicarrier signal having a number of frequency-discrete subcarriers and carrying inserted information converted by a multicarrier method to frequency-discrete modulation-specific modulation symbols, said system comprising:

means for superimposing on each frequency-discrete subcarrier of the multicarrier signal predetermined test disturbances to produce a deliberately disturbed multicarrier signal;

means for comparing disturbed modulation symbols in the deliberately disturbed multicarrier signal with undisturbed, modulation-specific modulation symbols, to derive subcarrier-specific error information;

means for deriving correction information representing the subcarrier-specific disturbances as a function of the predetermined test disturbances and the subcarrier-specific error information; and

means for correcting the frequency-discrete subcarriers of the multicarrier signal based on the correction information.

REMARKS

This Preliminary Amendment is submitted to improve the form of the English translation as filed. It is respectfully requested that this Preliminary Amendment be entered in the above-referenced application.

In accordance with the foregoing, claims 1-15 have been canceled and claims 16-30 have been added. Thus, claims 16-30 are pending and are under consideration.

A substitute specification is also being filed herewith. The substitute specification is accompanied by a marked-up copy of the original specification.

If there are any questions regarding these matters, such questions can be addressed by telephone to the undersigned. Otherwise, an early action on the merits is respectfully solicited.

If any further fees are required in connection with the filing of this Preliminary Amendment, please charge same to our Deposit Account No. 19-3935.

Respectfully submitted,

STAAS & HALSEY LLP

Date: 10/1/01

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Substitute Specification

TITLE OF THE INVENTION

METHOD AND SYSTEM FOR RECEIVING MULTICARRIER SIGNALS HAVING A NUMBER OF FREQUENCY-DISCRETE SUBCARRIERS

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention is directed to wireless communications networks, based on radio channels, in particular in point-to-multipoint radio feeder networks.

2. Description of the Related Art

[0002] In wireless communications networks, based on radio channels, in particular in point-to-multipoint radio feeder networks - also referred to as "Radio In The Local Loop" or "RLL" - a number of network termination units are each connected via one or more radio channels to a base station - also referred to as "Radio Base Station" or "RBS". For example, a wireless feeder network for wireless voice and data communication is described on pages 36, 37 of telecom report No. 18 (1995), Issue 1 "Drahtlos zum Freizeichen" which means "Wireless for Calling". The described communications system is an RLL subscriber access in conjunction with a modern broadband infrastructure - for example "Fiber to the curb" - which can be implemented in a short time and without major effort, instead of laying wire-based connecting cables. The network termination units RNT associated with the individual subscribers are connected via the "radio channel" transmission medium and the base station RBS to a higher-level communications network, for example to the ISDN-oriented landline network.

[0003] The increasingly widespread use of multimedia applications means that high-bit-rate data streams have to be transmitted quickly and reliably via communications networks, in particular via wireless communications networks and via mobile radio systems, with the radio transmission systems, which are based on a "radio channel" transmission medium which is susceptible to disturbances and whose transmission quality is difficult to assess, being subject to stringent requirements. One transmission method for transmitting broadband data streams - for example video data streams - is, for example, the OFDM transmission method which is

based on a multicarrier method - also referred to as Orthogonal Frequency Division Multiplexing OFDM. In the OFDM transmission technique, the information to be transmitted or the data stream to be transmitted is subdivided or parallelized between a number of subchannels or subcarriers within the radio channel, with the information to be transmitted in each case being transmitted at a relatively low data rate, but in parallel in an additively superimposed form. The OFDM transmission technique is used, for example, for digital terrestrial broadcast radio - also referred to as Digital Audio Broadcasting DAB - and for digital terrestrial television - also referred to as Digital Terrestrial Video Broadcasting DTVB. In particular, the OFDM transmission technique is intended to be used in future wireless local communications networks - also referred to as Wireless LAN or WLAN - and in future mobile radio communications networks - for example UMTS. The OFDM transmission technique will also be used in future access methods such as MC-SSMA - Multi-Carrier Spread Spectrum Multiple Access - or MC-CDMA - Multi-Carrier CDMA.

[0004] The OFDM transmission method is described in more detail in Figure 6 on page 46 of the document "Mitteilungen der TU-Braunschweig, Mobilfunktechnik für Multimedia-Anwendungen", Professor H. Rohling, Year XXXI, Issue 1-1996, the title of which means "Reports from Brunswick Technical University, Mobile Radio Technology for Multimedia Applications". In this case, based on a serial datastream in the transmitter, serial/parallel conversion is carried out for modulation of the, for example, n subcarriers, with a binary code word with a word length k - the word length k is dependent on the modulation method used - being formed in each case for the i-th OFDM block in time with the block length T' and the j-th subcarrier. A transmitter-specific modulation method is used to form the corresponding complex modulation symbols - also referred to as transmission symbols in the following text - from the code words that have been formed, with a transmission symbol being allocated to each of the k subcarriers at each time i. The separation between the individual subcarriers is defined by $\Delta f = 1\text{-}T'$, thus guaranteeing the orthogonality of the individual subcarrier signals in the interval (0,T') that is used. The oscillations of the individual subcarriers are multiplied by the corresponding modulation symbols or transmission symbols, and the modulation products that are formed are then added, to produce the corresponding time-discrete transmission signal for the i-th OFDM block in time. This transmission signal is calculated directly from the modulation symbols or transmission symbols of the individual subcarriers under consideration by Inverse, Discrete Fourier Transformation - IDFT. In order to minimize intersymbol interference, each OFDM block is preceded by a guard interval T_G in the time domain which results in the

time-discrete OFDM signal being lengthened in the interval ($-T_G$, 0) - see “Mitteilungen der TU-Braunschweig, Mobilfunktechnik für Multimedia-Anwendungen”, which means "Report from Brunswick Technical University, Mobile Radio Technology for Multimedia Applications," Figure 7. The guard interval T_G that is inserted advantageously corresponds to the maximum delay time difference that occurs between the individual propagation paths which occur during radio transmission. The removal of the added guard interval T_G at the receiver end avoids, for example, any interference between the i-th OFDM block and the OFDM signal which is adjacent in time at the time i-1, so that the transmission signal is received over all the circuitous paths in the interval (0,T'), and the orthogonality is fully maintained between the subcarriers in the receiver. If there are a large number of subcarriers - for example n = 256 subcarriers - and the symbol durations $T = T' + T_G$ are correspondingly long, then the duration T_G is short in comparison to T, so that the insertion of the guard interval efficiently has no significant adverse effect on the bandwidth, and the resultant overhead is only small. After sampling of the transmission signal, received at the input of the receiver in baseband - by an A/D converter - and after extraction of the interval being used - that is to say after removal of the guard interval T_G - a Discrete Fourier Transformation - DFT - is used to transform the received transmission signal to the frequency domain, that is to say the received modulation symbols and the received symbols are established. A suitable demodulation method is used to produce the corresponding received code words from the established received symbols and the received serial datastream is formed by parallel/serial conversion from these code words. The avoidance of intersymbol interference when using OFDM transmission methods considerably reduces the computation effort in the respective receiver, as a result of which the OFDM transmission technique is used, for example, for terrestrial transmission of digital television signals - for example for transmission of broadband datastreams at a transmission rate of 34 Mbps per radio channel.

[0005] Absolute or differential modulation methods and corresponding coherent or incoherent demodulation methods are used for transmission of the serial datastream to be transmitted using the OFDM transmission method. Examples of an absolute modulation method include 4-QAM or 16-QAM - Quadrature Amplitude Modulation. Although the orthogonality of the subcarriers is fully maintained when the OFDM transmission method is used to transmit the transmission signal that has been formed via the only “radio channel” transmission medium, the transmission characteristics of the radio channel result in the transmitted, frequency-discrete or frequency-selective transmission symbols being varied both in phase and amplitude. The

amplitude and phase influence of the radio channel affects the individual subcarriers, which each have a very narrow bandwidth, on a subcarrier-specific basis; furthermore, noise signals are additively superimposed on the transmitted user signal. When using coherent demodulation methods, channel estimation is required which, depending on the quality requirements, involves a considerable technical and financial implementation penalty and, furthermore, reduces the performance of the transmission system. It is advantageous to use differential modulation methods and corresponding incoherent demodulation methods in which there is no need for complex radio channel estimation. In differential modulation methods the information to be transmitted is not transmitted directly by selection of the modulation symbols or of the frequency-discrete transmission symbols, but by changing the frequency-discrete transmission symbols, which are adjacent in time, on the same subcarrier. Examples of differential modulation methods include 64-step 64-DPSK - Differential Phase Shift Keying - and 64-DAPSK - Differential Amplitude and Phase Shift Keying. In 64-DAPSK, both the amplitude and the phase are differentially modulated at the same time.

[0006] If there are major delay time differences between the individual signal paths, that is to say when severe multi-path propagation occurs, different attenuation levels, dependent on the transmission channel, with attenuation differences of up to 20 dB or more, may occur between the individual received subcarriers. The received subcarriers having high attenuation levels, or subcarriers with low S/N ratios - also referred to as the signal power-to-noise power ratio - have a very high symbol error rate, as a result of which the overall bit error rate over all the subcarriers rises considerably. In the case of subcarriers modulated using coherent modulation methods, it is already known for the attenuation losses caused by the frequency-selective transmission characteristics of the transmission medium - also referred to as the transfer function H(f) - to be corrected at the receiving end by using the inverse transfer function - also referred to as 1/H(f), with the frequency-selective attenuation losses being determined, for example, by evaluating transmitted reference pilot tones, which are each associated with specific subcarriers.

[0007] Normally, OFDM signals arriving at a receiver are mixed down to the intermediate frequency band or baseband by a local oscillator in a radio-frequency unit - also referred to as an RF frontend.

[0008] The respective local oscillators at the transmitting end and at the receiving end, have different frequency fluctuations and different phase noise depending on the quality and the Q

factor. OFDM signals in particular are highly susceptible to frequency fluctuations and phase noise, which are produced in particular in low-cost LO oscillators, so they result in loss of the orthogonality between the adjacent subcarriers in the frequency domain. The phase noise from a local oscillator causes disturbances in the demodulated baseband signal resulting, in particular, in the production of a Common Phase Error - also referred to as CPE interference or disturbances - and "Inter Carrier Interference" - also referred to as ICI disturbances in the baseband signal.

[0009] CPE disturbances rotate all the subcarriers in an OFDM received signal through a constant phase difference, in which case the phase difference can be estimated, and the OFDM signal can be corrected accordingly, with minimal effort. On the other hand, ICI disturbances cause mutual interference between the adjacent subcarriers in the frequency domain, with the respective extent of such disturbances being dependent on the nature of the information being transmitted. ICI disturbances are produced in the convolution of the individual subcarriers with the local oscillator carrier signal, which is subject to phase noise. If the same information is transmitted on each subcarrier, the same ICI interference is additively superimposed on each subcarrier. During normal operation, each subcarrier is subject to different amplitude fluctuations, which result in different ICI disturbances being produced in the individual subcarriers, depending on the modulation method being used and on the data being transmitted. The received OFDM signal is a complicated additive superimposition of a very large number of signal elements, so that the ICI interference can be established directly only by increased effort.

[0010] Oscillators with low phase noise - also referred to as pure phase oscillators - are available, but these are either very expensive or have a minimal trimming range, and which thus require complex additional baseband circuits.

SUMMARY OF THE INVENTION

[0011] The invention is based on the object of designing a low-cost way of transmitting information using a multicarrier method and, in particular, of achieving effective utilization of the transmission resources available in the transmission medium.

[0012] In the method according to the invention for receiving a multicarrier signal having a number of frequency-discrete subcarriers, the information to be transmitted is converted by a

multicarrier method to frequency-discrete modulation symbols, and is inserted into the multicarrier signal. The individual frequency-discrete subcarriers of the multicarrier signal transmitted via a transmitter medium are each subject to subcarrier-specific disturbances caused by adjacent subcarriers in the frequency domain. The major aspect of the method according to the invention is that the subcarriers in the received multicarrier signal are additionally deliberately subjected to test disturbances. The modulation symbols contained in the deliberately disturbed multicarrier signal are compared with undisturbed modulation-specific modulation symbols, and subcarrier-specific error information is derived from the comparison results. Correction information which represents subcarrier-specific disturbances is derived as a function of the predetermined test disturbances and as a function of the derived subcarrier-specific error information. The subcarriers in the received multicarrier signal are corrected in accordance with the determined correction information.

[0013] The major advantage of the method according to the invention is that the compensation according to the invention for the subcarrier-specific disturbances or ICI disturbances contained in the received multicarrier signal means that particularly low-cost local oscillators can be used in the respective transmitting and receiving devices. Such oscillators may, for example, be based on gallium arsenide and can be produced with the minimum financial cost and technical complexity using MMIC. Furthermore, no additional insertion of redundant information is required at the transmission end for estimation of the ICI disturbances or to establish correction information in order to implement the method according to the invention, thus allowing effective utilization of the transmission resources available in the transmission medium to be achieved.

[0014] The received symbols which represent frequency-discrete subcarriers are advantageously derived from the received multicarrier signal. In this advantageous refinement, k differently defined reference disturbance information items are provided, in which case, for each reference disturbance information item, the received symbols in the subcarriers which are in each case adjacent to at least some of the subcarriers in the frequency domain are each subjected to disturbances from the reference disturbance information, and the disturbed received symbols in the adjacent subcarriers are then additively superimposed (a) as deliberate test disturbances on the received symbol in the additionally disturbed subcarrier. The additionally deliberately disturbed received symbols are each compared with the closest modulation-specific modulation symbol, and subcarrier-specific error information is formed (b) as a function of the comparison results, and disturbance-information-specific sum error information is formed (c) from the subcarrier-specific error information. The k reference

disturbance information items and the k sum error information items are then used to derive (d) the correction information . This advantageous refinement allows the correction information for estimating the ICI disturbances to be established very accurately, since the correction information has been derived by averaging over all the subcarriers in the received multicarrier signal.

[0015] According to one advantageous refinement of the method according to the invention, the correction information (ici_{opt}) is determined in the course of an iterative search, with the k reference disturbance information items (ici1...4) being established in the course of the iterative search, and steps (a) to (c) being repeated until a minimum value of the disturbance-information-specific sum error information (ε_{min}) is determined, and the correction information (ici_{opt}) has been derived from this . Determination of correction information (ici_{opt}) using the iterative search represents a highly stable method.

[0016] According to a further advantageous refinement of the method according to the invention, the additionally deliberately disturbed received symbols are in each case corrected by equalization as a function of frequency-selective transmission characteristics of the transmission medium before the comparison with the respective closest modulation-specific modulation symbol. Equalizing the received multicarrier signal to correct for the frequency-selective transmission characteristics of the transmission medium means that any errors which may have occurred in the comparison of the deliberately disturbed received symbols with the respective closest modulation-specific modulation symbols are minimized, and the quality of the determined correction information is thus improved.

[0017] Advantageously, once steps (a) to (d) have each been carried out for each reference disturbance information item the received symbols of the subcarriers which are each further away from at least some of the subcarriers in the frequency domain are each subjected to disturbances from the reference disturbance information, and the disturbed received symbols are then additively superimposed as deliberate test disturbances on the received symbol of the additionally disturbed subcarrier (a'). Steps (b) to (d) are then carried out. Giving additional consideration to those subcarrier-specific disturbances which are in each case caused by adjacent carriers that are further away in the frequency domain further improves the quality of the determined correction information.

[0018] In order to achieve a further improvement in the process of establishing the correction information, according to a further advantageous refinement of the method according to the invention, the received symbols which have been corrected using the correction information are demodulated. Errors are identified in the demodulated received symbols using error identification information inserted into the transmitted information, and identified, erroneous received symbols are corrected. When errors are identified, steps (b) to (d) are carried out once again, with the corrected received symbols being used for determining the correction information.

[0019] Further advantageous refinements of the method and system according to the invention for receiving a multicarrier signal having a number of frequency-discrete subcarriers are described below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] The method according to the invention will be explained in more detail in the following text with reference to four drawings, in which:

Figure 1 is graph of a disturbance model on which the method according to the invention is based, which is used to illustrate the mutual subcarrier-specific interference between subcarriers in a multicarrier signal which are adjacent in the frequency domain,

Figure 2 is a block diagram of a circuit using the method according to the invention,

Figure 3 is a block diagram of an advantageous refinement of a circuit for additive superimposition of reference disturbance information, and test disturbances derived from it, on the respective subcarriers in a received multicarrier signal, and

Figure 4 is a graph of an error curve or correction function from which the correction information to minimize the subcarrier-specific disturbances in a received multicarrier signal is derived.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0021] Figure 1 is graph of a disturbance model, in the frequency domain, to illustrate the problem on which the method according to the invention is based. The disturbance model shows, in detail form, a number of subcarriers st_{i-1}, st_i, st_{i+1} in a multicarrier signal ms which has, in particular, n subcarriers st1...n and is formed using a multicarrier method. It is assumed in

the following text that the multicarrier signal is produced using an OFDM transmission method. Originating from each subcarrier st_i, subcarrier-specific disturbances icix are produced in those subcarriers st_{i-1} and st_{i+1} which are adjacent in the frequency domain, and these disturbances are indicated by small arrows in the disturbance model. Conversely, the centrally arranged i-th subcarrier st_i is influenced by the subcarrier-specific disturbances - indicated by $icix_{-1}$ and $icix_{+1}$ in Fig. 1 - caused by the two adjacent subcarriers st_{i-1} and st_{i+1}, with the respective i-th subcarrier st_i in each case having the subcarrier-specific disturbances $icix_{-1}$, $icix_{+1}$ which are produced actively superimposed on it. As shown in Fig. 1, the received multicarrier signal ms is a complicated superimposition of a very large number of signal elements, so that it is no longer possible to establish directly the subcarrier-specific disturbances icix originating from the individual subcarriers st1...n.

[0022] Figure 2 is a block diagram of a circuit in a receiving unit E and by which the subcarrier-specific disturbances icix - also referred to as ICI disturbances in the following text - contained in the received OFDM signal ms are estimated, with the received OFDM signal ms then being corrected by equalization as a function of the estimation result. The block diagram shows a receiving unit E which has a receiving antenna A and may, for example, be a modular component in base stations or network termination units, which act as receiving systems in wireless communications networks. A radio-frequency converter unit HFU is connected via an input EH to the receiving antenna A which is fitted externally on the receiving unit E. A local oscillator LO in the radio-frequency converter unit HFU has oscillator-specific phase noise φ_{LO}. The radio-frequency converter HFU is connected via an output AH to an input EW of a converter unit WAS. The converter unit WAS performs analog/digital conversion and subsequent serial/parallel conversion (A/D, S/P) of an incoming received signal ms'. The converter unit WAS has n outputs AW1...n, which are connected to corresponding inputs EF1...n of a transformation unit FFT for carrying out a discrete "Fast Fourier Transformation". The transformation unit FFT is connected via n outputs AF1...n to corresponding inputs EP1...n of a parallel/serial converter PSW.

[0023] The parallel serial converter PSW is connected via an output AP to one input ER of each of four parallel-arranged reference modules RM1...4, by which four defined disturbance signals, or reference disturbance information items ici1...4 representing them, are added to the received OFDM signal ms. To do this, each of the four reference modules RM1...4 has a disturbance unit STE, each of which is associated with one of the reference disturbance information items ici1...4, and by which the individual subcarriers st1...n in the received OFDM signal ms have the

respectively associated reference disturbance information ici1...4 additively superimposed on them. Each reference module RM1...4 also has an equalizer unit EZ for linear equalization of the received OFDM signal for the radio channel characteristics H(f), and an error detector unit FE in order to establish disturbance-information-specific sum error information $s\varepsilon 1...4$. Each error detector unit FE is connected via an output AF to an output AR of the respective reference module RM1...4. Each of the four reference modules RM1...4 is connected via the output AR to an input EA1...4 of an evaluation unit ASW.

[0024] The output AP of the parallel/serial converter PSW is also connected to an input EV of a delay unit VE, which delays the received OFDM signal ms by a predetermined time constant $\Delta\tau$. The delay unit VE is connected via an output AV to the input EK of correction unit KE. The correction unit KE has a control input SE, which is connected to a control output SA of the evaluation unit ASW. The correction unit AE is connected via an output AK to an input EE of a further equalizer unit EZ, which is connected via an output AE to an input AD of a demodulator DMOD. The demodulator DMOD has an output AD, to which the demodulated received signal is passed on as a digital data signal di.

[0025] The method according to the invention will be explained in the following text with reference to the circuit illustrated in Fig. 2.

[0026] In a transmitter which is not illustrated, a multicarrier method, for example, an OFDM transmission method, is used to convert the information to be transmitted, by a phase-modulating modulation method - for example 4QAM or 16QAM - to corresponding modulation symbols, which are then converted to an OFDM signal ms, which has a number of frequency-discrete subcarriers st1...n, and this is transmitted via the "radio channel" transmission medium FK to the receiving unit E. The radio channel FK has frequency-selective transmission characteristics H(f), which distort the amplitude and phase of the OFDM signal ms. The transmitted OFDM signal ms is received via the receiving antenna A, which is mounted externally on the receiving unit E, and is supplied to the radio-frequency converter unit HFU. The received OFDM signal ms is down-mixed to the intermediate-frequency band by the local oscillator LO in the radio-frequency converter unit HFU, with the phase noise φ_{LO} in the local oscillator LO producing the subcarrier-specific disturbances icix in the individual subcarriers st1...n in the received OFDM signal ms. The OFDM signal ms' which has been down-mixed to the intermediate-frequency band, is analog/digital converted by the converter unit WAS, and is then parallelized by serial/parallel conversion to corresponding n-time-discrete samples zs1...n

which represent the digital OFDM signal. The discrete "Fast Fourier Transformation" that is carried out in the transformation unit FFT is used to calculate the corresponding n received symbols es1...n from the n time-discrete samples zs1...n, and these are then converted by the parallel/serial converter PSW to a serial datastream es1...n. It should be noted that the serial/parallel and parallel/serial converter illustrated in Fig. 2 is not absolutely essential, since many modern microprocessors already process the incoming and outgoing information in serial form in order to carry out the "Fast Fourier Transformation". The received symbols es1...n which are each passed to the output AW of the parallel/serial converter PSW and represent the currently received subcarriers st1...n in the received OFDM signal ms, are each supplied to the four reference modules RM1...4.

[0027] The operation of the reference modules RM1...4 will be explained in more detail in the following text.

[0028] The disturbance units STE in the reference modules RM1...4 are used in each case to superimpose reference disturbance information ici1...4, which represents subcarrier-specific disturbances icix, on the transmitted received symbols es1...n. To this end, using the reference disturbance information ici1...4, subcarrier-specific disturbances $icix_{-1}$, $icix_{+1}$ - also referred to as defined test disturbances - are derived from the respective subcarriers st_{i-1}, st_{i+1} adjacent to an i-th subcarrier st_i, for example by multiplication by the reference disturbance information ici1...4 - and the two derived test disturbances $icix_{-1}$, $icix_{+1}$, are then additively superimposed on the centrally arranged i-th subcarrier st_i.

[0029] By way of example, Fig. 3 shows a circuitry embodiment of the disturbance unit STE for forming the test disturbances icix and for additively superimposing the test disturbances icix that are formed on the subcarriers st1...n. The disturbance unit STE has three timers T1...3, which are used to delay the received symbols es1...n, which arrive in serial form and represent the individual subcarriers st1..n. Arranging the three timers T1...3 in series means that three subcarriers st_{i-1}, st_i and st_{i+1}, which are adjacent in the frequency domain and are represented by the received symbols es1...n, are in each case available at the same time. The first and the third timer T1, T3 are each connected via an output AT to an input EM of a multiplier M, which is used to multiply the respective received symbol es1...n currently stored in the corresponding timer T1, T3 by the reference disturbance information ici1...4 associated with the respective reference module RM1...4. The two multipliers M are connected via in each case one output AM to inputs EA of an adder ADD, to which an output AT of the second timer T2 is also

connected. The circuit illustrated in Fig. 3 is used to multiply the respective subcarriers st_{i-1}, st_{i+1}, which are adjacent about an i-th subcarrier, or the received symbols es1...n representing them by the respectively associated reference disturbance information ici1...4, and the two multiplication products which each represent test disturbances $icix_{-1}$, $icix_{+1}$ added to the i-th subcarrier st_i, or to the received symbol es1...n representing it. Depending on the respective mathematical sign of the individual reference disturbance information items ici1...4, the test disturbances $icix_{-1}$, $icix_{+1}$ which are formed are added to or subtracted from the respective i-th subcarrier st_i, which the disturbance process which is illustrated in Fig. 1, based on the phase noise φ_{LO} of the local oscillator LO in the radio-frequency converter unit HFU being reversed by the subtraction of a test disturbance icix.

[0030] In order to allow the ICI disturbances ici0 caused by the phase noise in the oscillator LO to be established or estimated accurately, the received symbols es'1...n to which the various reference disturbance information items ici1...4 have been applied are also linearly equalized by the equalizer unit EZ. In order to allow linear equalization to correct for the transmission characteristics of the transmission medium, the transfer function H(f) of the radio channel FK is established, for example using pilot symbols. The received symbols es'1...n are then multiplied by the inverse transfer function 1/H(f). The equalized received symbols es"1...n are then supplied to the error detector unit FE.

[0031] In the error detection unit FE, the received symbols es"1...n supplied to it are each compared with the next-best or most probable modulation symbol - the set of modulation symbols is in each case dependent on the modulation method used - and the subcarrier-specific error information item $\Delta\varepsilon$1..n is formed for each received symbol es"1...n representing the difference or the interval between the received symbol es"1...n and the next-best modulation symbol. The subcarrier-specific error information items $\Delta\varepsilon$1..n determined for each reference disturbance information item ici1...4 over all the subcarriers st1...n are then added to form a disturbance-information-specific sum error information item sε1...4, where sε1...4 = $\sum|\Delta\varepsilon 1...n|$. The four disturbance-information-specific sum error information items sε1...4 defined in the four reference modules RM1...4 are each passed on to the evaluation unit ASW.

[0032] In the evaluation unit ASW, correction information ici_{opt} is derived, in accordance with the error curve illustrated in Fig. 4, from the four predetermined reference disturbance information items ici1...4 and from the four disturbance-information-specific sum error information items sε1...4 defined in the four reference modules RM1...4. The error curve at the same time

represents a correction function and is illustrated in a two-dimensional coordinate system, with the reference disturbances ici1...4, or the test disturbances icix derived from them, being plotted on the abscissa, and the respectively defined, disturbance-information-specific sum error information items $s\varepsilon 1...4$ being shown on the ordinate - where $s\varepsilon 1...4 = \sum|\Delta\varepsilon 1...n(ici1...4)|$. For the exemplary embodiment it is assumed that the sums of the respective subcarrier-specific error information items $\Delta\varepsilon 1...n$, that is to say the disturbance-information-specific sum error information items $s\varepsilon 1...4 = \sum|\Delta\varepsilon 1...n|$, rise linearly as the ICI interference increases, that is to say as the magnitudes of the reference disturbance information items ici1...4 rise, since the disturbance model illustrated in Fig. 1 is based on additive disturbance terms. Ideally, when a multicarrier signal ms is received without any ICI interference, the sum of the subcarrier-specific error information items $\Delta\varepsilon 1...n$ has a minimum value $s\varepsilon_{min}$ with the minimum value $s\varepsilon_{min}$ turning to zero in an ideal communications system, without any additively superimposed Gaussian noise - AWGN - and without any estimation error $\Delta H(f)$ for the radio channel FK. In real systems, the minimum value $s\varepsilon_{min}$ has a value that is not equal to zero. Due to the phase noise from the local oscillator LO in the radio-frequency-converter unit HFU, the received symbols es1...n which are produced at the output of the parallel/serial converter PSW have ICI interference which cannot be recorded precisely, and which is represented by the value ici0 in Fig. 4. Based on this ICI interference ici0, which cannot be measured, this results in subcarrier-specific error information $\Delta\varepsilon 1...n$, whose sum $\sum|\Delta\varepsilon 1...n|$ gives the value $s\varepsilon 0$, which is likewise shown in Fig. 4, where $s\varepsilon 0 \geq s\varepsilon_{min}$.

[0033] Figure 4 shows the intersection of the ICI interference ici0 which is contained in the received symbols es1...n but cannot be established with any great accuracy, and the sum, resulting from this, of the subcarrier-specific error information $s\varepsilon 0 = \sum|\Delta\varepsilon 1...n(ici0)|$ by a point AP. Starting from this point, or this point of origin AP, the received symbols es1...n each have the four different reference disturbance information items ici1...4 or test disturbances icix applied to them in the described manner according to the invention - in the respective reference modules RM1...4- and the disturbance-information-specific sum error information items $s\varepsilon 1...4$ are then determined. As shown in Fig. 4, the first and the third reference disturbance information items ici1,3 each represent a very low level of ICI interference in each case with the opposite mathematical sign, while the second and the fourth reference disturbance information items ici2,4 each represent a relatively high ICI interference level. A linear relationship is assumed between the reference disturbance information ici1...4, or the disturbance signals icix derived from them, and the disturbance-information-specific sum error information items $s\varepsilon 1...4$

resulting from them. The linear relationship is indicated in the error curve or correction function illustrated in Fig. 4 by a linear characteristic $\sum|\Delta\varepsilon 1...n|$ whose gradient is S. By calculating the gradient S of the correction function, it is possible to establish from the known output variables - in this case from the reference disturbance information items ici1...4 - and the disturbance-information-specific sum error information items sε1...4 established with the aid of the reference modules RM1...4, that correction information item ici_{opt} which gives the sum of the subcarrier-specific error information items $\sum|\Delta\varepsilon 1...n(ici_{opt})|$ the minimum value $s\varepsilon_{min}$; that is to say the specific correction information item ici_{opt} can be used to produce that disturbance icix which minimizes the ICI interference present in the received OFDM signal.

[0034] The correction information can be derived from the known variables using the following calculation rule:

$$s\varepsilon_0 = \frac{(s\varepsilon 1 + s\varepsilon 3)}{2} \qquad (1)$$

$$\Delta s\varepsilon = \frac{(s\varepsilon 1 - s\varepsilon 3)}{2} \qquad (2)$$

$$S = \frac{\Delta s\varepsilon}{ici3} = \frac{s\varepsilon 1 - s\varepsilon 3}{ici1 - ici3} \qquad (3)$$

$$s\varepsilon_{min} = s\varepsilon_0 + S \bullet ici_{opt} \qquad (4)$$

$$s\varepsilon 4 = \varepsilon_{min} - S \bullet (ici4 - ici_{opt}) \qquad (5)$$

It follows from equations (1) to (5) that:

$$ici_{opt} = \left(\frac{s\varepsilon 4 - s\varepsilon 0}{2(s\varepsilon 1 - s\varepsilon 3)}\right) \bullet (ici1 - ici3) + \frac{ici4}{2} \qquad (6)$$

$$ici_{opt} = \left(\frac{s\varepsilon 4 - \frac{(s\varepsilon 1 + s\varepsilon 3)}{2}}{2(s\varepsilon 1 - s\varepsilon 3)}\right) \bullet (ici1 - ici3) + \frac{ici4}{2} \qquad (7)$$

where ici1, ici2 ≥ 0

ici3, ici4 ≤ 0

[0035] If the point of origin AP (ici0, sε0) is in the left-hand section of the error curve or correction function $\sum|\Delta\varepsilon 1...n|$, or in the second quadrant of the coordinate system, the calculation rule shown above must be adapted appropriately. The effort for calculating the correction information ici_{opt} is negligible since it is calculated only once after receiving an OFDM signal - after establishing the received symbols es1...n.

[0036] The calculated correction information ici_{opt} is passed on to the correction unit KE. The received OFDM signal ms and the received symbols es1...n produced at the output of the parallel/serial converter PSW are delayed in the delay unit VE by the time constant $\Delta\tau$, with the magnitude of the time constant $\Delta\tau$ being such that the received symbols es1...n are not transmitted to the correction unit KE until the correction information ici_{opt} has been calculated and passed on to the correction unit KE. In the correction unit KE, the delayed received symbols ves1...n have the optimized disturbance icix additively superimposed on them, and are thus corrected, in the manner already described. The corrected received symbols ves'1...n are then multiplied in the equalizer unit EZ by the inverse of the transfer function 1/H(f) of the radio channel FK, and are passed on to the demodulator DMOD. In the demodulator DMOD, the equalized received symbols ves"1...n are demodulated, and are converted to a digital datastream di.

[0037] If the ICI interference level in the received OFDM signal is very high, then, according to one advantageous development of the method according to the invention, the ICI interference caused between subcarriers that are further away - for example between the subcarriers st_{i-2}, st_i and st_{i+2} is also corrected by equalization. An interactive method could be used for this purpose, in which, in a first step, those subcarriers which are immediately adjacent in the frequency domain - in this case the subcarriers st_{i-1}, st_i and st_{i+1} - are corrected by equalization in the described manner. In a second step in the same method, the ICI interference caused by those subcarriers which are further away in the frequency domain - in this case the subcarriers st_{i-2}, st_i and st_{i+2} - is corrected by equalization. If necessary, the iteration method can also be extended to subcarriers st_{i-b}, st_i and st_{i+b}, where $b > 1$, which are further away in the frequency domain.

[0038] Furthermore, if the ICI interference level is very high, the received symbols es1...n may have very large symbol errors. When these received symbols es1...n which are subject to errors are compared with the respectively next-best modulation symbol representing the nominal value - also referred to as the estimated value - the received symbols es1...n may be compared with the wrong modulation symbol, which would lead to considerable errors in the

calculation of the sum of the carrier-specific error information items $\sum|\Delta\varepsilon 1...n|$. Incorrect correction information ici_{opt} would be derived from the incorrectly determined disturbance-information-specific sum error information items $s\varepsilon 1...4 = \sum|\Delta\varepsilon 1...n|$. In the worst case, this would cause an increase in the bit errors in the demodulated datastream di.

[0039] According to a further advantageous refinement of the method according to the invention - not illustrated - an error handling routine - also referred to as Forward Error Correction, FEC - is provided, which is used to investigate the demodulated datastream di for any bit errors which may have occurred. According to this advantageous refinement of the method according to the invention, an additional interaction method is carried out when big errors are identified, in which incorrectly identified received symbols are corrected and the sum of the carrier-specific error information items $\sum|\Delta\varepsilon 1...n|$ is formed once again using the corrected received symbols. This embodiment variant can be used in particular for modulation methods having a relatively large number of stages.

[0040] According to one further refinement variant of the method according to the invention, only some of the received symbols es1...n derived from the received multicarrier signal ms are used for establishing the correction information ici_{opt}, thus minimizing the complexity for calculating the correction information ici_{opt}, and hence minimizing the delay to the received multicarrier signal ms, that is to say the delay constant $\Delta\tau$.

[0041] According to one advantageous development, the method according to the invention is used together with an error handling routine. In this case, no equalization of the ICI interference in the received multicarrier signal is carried out initially. In a first step, the received multicarrier signal is first of all demodulated, and the demodulated datastream di is then investigated for bit errors, using the error handling routine. Only if bit errors that are identified can no longer be corrected is the method according to the invention carried out, with bit errors that have been identified, that is to say incorrect received symbols es1...n, not being included in the formation of the disturbance-information-specific sum error information items $s\varepsilon 1...4 = \sum|\Delta\varepsilon 1...n|$. This may be done, for example, by masking out the incorrect subcarriers st1...n or received symbols es1...n or by appropriate correction of the faulty received symbols es1...n. This advantageous development can be repeated iteratively until all the ICI interference has been corrected by equalization.

[0042] According to one alternative refinement variant of the method according to the invention, based on the error curve illustrated in Fig. 4, the minimum sum ε_{min} of the subcarrier-specific error information items $\sum|\Delta\varepsilon 1...n|$ is determined by an iterative search - with a defined step width - using two small reference disturbance information items ici1, 3 or test disturbances.

SUBSTITUTE ABSTRACT

ABSTRACT OF DISCLOSURE

METHOD AND SYSTEM FOR RECEIVING MULTICARRIER SIGNALS HAVING A NUMBER OF FREQUENCY-DISCRETE SUBCARRIERS

In a received multicarrier signal which is subject to subcarrier-specific disturbances caused by adjacent subcarriers, the subcarriers are additionally deliberately subjected to disturbances, and correction information which represents the carrier-specific disturbances is derived from the subcarriers which have been additionally deliberately subjected to disturbances and is then used to correct the received subcarriers. Low-cost oscillators can advantageously be used to provide cheap transmitting and receiving units.

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Marked-up Substitute Specification

[Description]

TITLE OF THE INVENTION

[METHOD, USE OF THE] METHOD AND [A RECEIVING ARRANGEMENT] SYSTEM FOR RECEIVING MULTICARRIER SIGNALS HAVING A NUMBER OF FREQUENCY-DISCRETE SUBCARRIERS

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention is directed to wireless communications networks, based on radio channels, in particular in point-to-multipoint radio feeder networks.

2. Description of the Related Art

[0002] In wireless communications networks, based on radio channels, in particular in point-to-multipoint radio feeder networks - also referred to as "Radio In The Local Loop" or "RLL" - a number of network termination units are each connected via one or more radio channels to a base station - also referred to as "Radio Base Station" or "RBS". For example, a wireless feeder network for wireless voice and data communication is described on pages 36, 37 of telecom report No. 18 (1995), Issue 1 "Drahtlos zum Freizeichen" [Wireless for calling] which means "Wireless for Calling". The described communications system is an RLL subscriber access in conjunction with a modern broadband infrastructure - for example "Fiber to the curb" - which can be implemented in a short time and without major effort, instead of laying wire-based connecting cables. The network termination units RNT associated with the individual subscribers are connected via the "radio channel" transmission medium and the base station RBS to a higher-level communications network, for example to the ISDN-oriented landline network.

[0003] The increasingly widespread use of multimedia applications means that high-bit-rate data streams have to be transmitted quickly and reliably via communications networks, in particular via wireless communications networks and via mobile radio systems, with the radio transmission systems, which are based on a "radio channel" transmission medium which is susceptible to disturbances and whose transmission quality is difficult to assess, being subject

to stringent requirements. One transmission method for transmitting broadband data streams - for example video data streams - is, for example, the OFDM transmission method which is based on a multicarrier method - also referred to as Orthogonal Frequency Division Multiplexing OFDM. In the OFDM transmission technique, the information to be transmitted or the data stream to be transmitted is subdivided or parallelized between a number of subchannels or subcarriers within the radio channel, with the information to be transmitted in each case being transmitted at a relatively low data rate, but in parallel in an additively superimposed form. The OFDM transmission technique is used, for example, for digital terrestrial broadcast radio - also referred to as Digital Audio Broadcasting DAB - and for digital terrestrial television - also referred to as Digital Terrestrial Video Broadcasting DTVB. In particular, the OFDM transmission technique is intended to be used in future wireless local communications networks - also referred to as Wireless LAN or WLAN - and in future mobile radio communications networks - for example UMTS. The OFDM transmission technique will also be used in future access methods such as MC-SSMA - Multi-Carrier Spread Spectrum Multiple Access - or MC-CDMA - Multi-Carrier CDMA.

[0004] The OFDM transmission method is described in more detail in Figure 6 on page 46 of the document "Mitteilungen der TU-Braunschweig, Mobilfunktechnik für Multimedia-Anwendungen" [Reports from Brunswick Technical University, Mobile Radio Technology for Multimedia Applications], Professor H. Rohling, Year XXXI, Issue 1-1996<u>, the title of which means "Reports from Brunswick Technical University, Mobile Radio Technology for Multimedia Applications"</u>. In this case, based on a serial datastream in the transmitter, serial/parallel conversion is carried out for modulation of the, for example, n subcarriers, with a binary code word with a word length k - the word length k is dependent on the modulation method used - being formed in each case for the i-th OFDM block in time with the block length T' and the j-th subcarrier. A transmitter-specific modulation method is used to form the corresponding complex modulation symbols - also referred to as transmission symbols in the following text - from the code words that have been formed, with a transmission symbol being allocated to each of the k subcarriers at each time i. The separation between the individual subcarriers is defined by $\Delta f = 1\text{-}T'$, thus guaranteeing the orthogonality of the individual subcarrier signals in the interval ~~[0,T']~~ <u>(0,T')</u> that is used. The oscillations of the individual subcarriers are multiplied by the corresponding modulation symbols or transmission symbols, and the modulation products that are formed are then added, to produce the corresponding time-discrete transmission signal for the i-th OFDM block in time. This transmission signal is calculated directly from the modulation

symbols or transmission symbols of the individual subcarriers under consideration by Inverse, Discrete Fourier Transformation - IDFT. In order to minimize intersymbol interference, each OFDM block is preceded by a guard interval T_G in the time domain which results in the time-discrete OFDM signal being lengthened in the interval $[-T_G, 0]$ $\underline{(-T_G, 0)}$ - see “Mitteilungen der TU-Braunschweig, Mobilfunktechnik für Multimedia-Anwendungen” [Report from Brunswick Technical University, Mobile Radio Technology for Multimedia Applications], which means "Report from Brunswick Technical University, Mobile Radio Technology for Multimedia Applications," Figure 7. The guard interval T_G that is inserted advantageously corresponds to the maximum delay time difference that occurs between the individual propagation paths which occur during radio transmission. The removal of the added guard interval T_G at the receiver end avoids, for example, any interference between the i-th OFDM block and the OFDM signal which is adjacent in time at the time i-1, so that the transmission signal is received over all the circuitous paths in the interval [0,T'] $\underline{(0,T')}$, and the orthogonality is fully maintained between the subcarriers in the receiver. If there are a large number of subcarriers - for example n = 256 subcarriers - and the symbol durations $T = T' + T_G$ are correspondingly long, then the duration T_G is short in comparison to T, so that the insertion of the guard interval efficiently has no significant adverse effect on the bandwidth, and the resultant overhead is only small. After sampling of the transmission signal, received at the input of the receiver in baseband - by an A/D converter - and after extraction of the interval being used - that is to say after removal of the guard interval T_G - a Discrete Fourier Transformation - DFT - is used to transform the received transmission signal to the frequency domain, that is to say the received modulation symbols and the received symbols are established. A suitable demodulation method is used to produce the corresponding received code words from the established received symbols and the received serial datastream is formed by parallel/serial conversion from these code words. The avoidance of intersymbol interference when using OFDM transmission methods considerably reduces the computation effort in the respective receiver, as a result of which the OFDM transmission technique is used, for example, for terrestrial transmission of digital television signals - for example for transmission of broadband datastreams at a transmission rate of 34 Mbps per radio channel.

[0005] Absolute or differential modulation methods and corresponding coherent or incoherent demodulation methods are used for transmission of the serial datastream to be transmitted using the OFDM transmission method. Examples of an absolute modulation method include 4-QAM or 16-QAM - Quadrature Amplitude Modulation. Although the orthogonality of the

subcarriers is fully maintained when the OFDM transmission method is used to transmit the transmission signal that has been formed via the only "radio channel" transmission medium, the transmission characteristics of the radio channel result in the transmitted, frequency-discrete or frequency-selective transmission symbols being varied both in phase and amplitude. The amplitude and phase influence of the radio channel affects the individual subcarriers, which each have a very narrow bandwidth, on a subcarrier-specific basis; furthermore, noise signals are additively superimposed on the transmitted user signal. When using coherent demodulation methods, channel estimation is required which, depending on the quality requirements, involves a considerable technical and financial implementation penalty and, furthermore, reduces the performance of the transmission system. It is advantageous to use differential modulation methods and corresponding incoherent demodulation methods in which there is no need for complex radio channel estimation. In differential modulation methods the information to be transmitted is not transmitted directly by selection of the modulation symbols or of the frequency-discrete transmission symbols, but by changing the frequency-discrete transmission symbols, which are adjacent in time, on the same subcarrier. Examples of differential modulation methods include 64-step 64-DPSK - Differential Phase Shift Keying - and 64-DAPSK - Differential Amplitude and Phase Shift Keying. In 64-DAPSK, both the amplitude and the phase are differentially modulated at the same time.

[0006] If there are major delay time differences between the individual signal paths, that is to say when severe multi-path propagation occurs, different attenuation levels, dependent on the transmission channel, with attenuation differences of up to 20 dB or more, may occur between the individual received subcarriers. The received subcarriers having high attenuation levels, or subcarriers with low S/N ratios - also referred to as the signal power-to-noise power ratio - have a very high symbol error rate, as a result of which the overall bit error rate over all the subcarriers rises considerably. In the case of subcarriers modulated using coherent modulation methods, it is already known for the attenuation losses caused by the frequency-selective transmission characteristics of the transmission medium - also referred to as the transfer function H(f) - to be corrected at the receiving end by using the inverse transfer function - also referred to as 1/H(f), with the frequency-selective attenuation losses being determined, for example, by evaluating transmitted reference pilot tones, which are each associated with specific subcarriers.

[0007] Normally, OFDM signals arriving at a receiver are mixed down to the intermediate frequency band or baseband by [means of] a local oscillator [arranged] in a radio-frequency unit - also referred to as an RF frontend.

[0008] The respective local oscillators [arranged] at the transmitting end and at the receiving end, have different frequency fluctuations and different phase noise depending on the quality and the Q factor. OFDM signals in particular are highly susceptible to frequency fluctuations and phase noise, which are produced in particular in low-cost LO oscillators, so they result in loss of the orthogonality between the adjacent subcarriers [arranged adjacent] in the frequency domain. The phase noise from a local oscillator causes disturbances in the demodulated baseband signal resulting, in particular, in the production of a Common Phase Error - also referred to as CPE interference or disturbances - and "Inter Carrier Interference" - also referred to as ICI disturbances in the baseband signal.

[0009] CPE disturbances rotate all the subcarriers in an OFDM received signal through a constant phase difference, in which case the phase difference can be estimated, and the OFDM signal can be corrected accordingly, with minimal effort. On the other hand, ICI disturbances cause mutual interference between the adjacent subcarriers [arranged adjacent] in the frequency domain, with the respective extent of such disturbances being dependent on the nature of the information being transmitted. ICI disturbances are produced in the convolution of the individual subcarriers with the local oscillator carrier signal, which is subject to phase noise. If the same information is transmitted on each subcarrier, the same ICI interference is additively superimposed on each subcarrier. During normal operation, each subcarrier is subject to different amplitude fluctuations, which result in different ICI disturbances being produced in the individual subcarriers, depending on the modulation method being used and on the data being transmitted. The received OFDM signal is a complicated additive superimposition of a very large number of signal elements, so that the ICI interference can be established directly only by increased effort.

[0010] Oscillators with low phase noise - also referred to as pure phase oscillators - are available, but these are either very expensive or have a minimal trimming range, and which thus require complex additional baseband circuits.

SUMMARY OF THE INVENTION

[0011] The invention is based on the object of designing a low-cost [means] way of transmitting information using a multicarrier method and, in particular, of achieving effective utilization of the transmission resources available in the transmission medium. [Based on a method and a receiving arrangement according to the features of the precharacterizing clauses of patent claims 1 and 15, the object is achieved by the characterizing features of these claims.]

[0012] In the method according to the invention for receiving a multicarrier signal having a number of frequency-discrete subcarriers, the information to be transmitted is converted by [means of] a multicarrier method to frequency-discrete modulation symbols, and is inserted into the multicarrier signal. The individual frequency-discrete subcarriers of the multicarrier signal transmitted via a transmitter medium are each subject to subcarrier-specific disturbances caused by adjacent subcarriers [arranged adjacent] in the frequency domain. The major aspect of the method according to the invention is that the subcarriers in the received multicarrier signal are additionally deliberately subjected to test disturbances. The modulation symbols contained in the deliberately disturbed multicarrier signal are compared with undisturbed modulation-specific modulation symbols, and [that correction] subcarrier-specific error information is derived from the comparison results. Correction information which represents subcarrier-specific disturbances is derived [from the subcarriers which have been additionally deliberately subjected to disturbances] as a function of the predetermined test disturbances and as a function of the derived subcarrier-specific error information. The [received, frequency-discrete] subcarriers in the received multicarrier signal are [then] corrected in accordance with the determined correction information.

[0013] The major advantage of the method according to the invention is that the compensation according to the invention for the subcarrier-specific disturbances or ICI disturbances contained in the received multicarrier signal means that particularly low-cost local oscillators can be used in the respective transmitting and receiving devices. Such oscillators may, for example, be based on gallium arsenide and can be produced with the minimum financial cost and technical complexity using MMIC. Furthermore, no additional insertion of redundant information is required at the transmission end for estimation of the ICI disturbances or to establish correction information in order to implement the method according to the invention, thus allowing effective utilization of the transmission resources available in the transmission medium to be achieved.

[0014] The received symbols which represent frequency-discrete subcarriers are advantageously derived from the received multicarrier signal. In this advantageous refinement, k differently defined reference disturbance information items are provided, in which case, for each reference disturbance information item, the received symbols in the subcarriers which are in each case [arranged] adjacent [around] to at least some of the subcarriers in the frequency domain are each subjected to disturbances from the reference disturbance information, and the disturbed received symbols in the adjacent subcarriers are then additively superimposed (a) as deliberate test disturbances on the received symbol in the additionally disturbed subcarrier. The additionally deliberately disturbed received symbols are each compared with the closest modulation-specific modulation symbol, and subcarrier-specific error information is formed (b) as a function of the comparison results, and disturbance-information-specific sum error information is formed (c) from the subcarrier-specific error information. The k reference disturbance information items and the k sum error information items are then used to derive (d) the correction information [- claim 3]. This advantageous refinement allows the correction information for estimating the ICI disturbances to be established very accurately, since the correction information has been derived by averaging over all the subcarriers in the received multicarrier signal.

[0015] According to one advantageous refinement of the method according to the invention, the correction information (ici_{opt}) is determined in the course of an iterative search, with the k reference disturbance information items (ici1...4) being established in the course of the iterative search, and steps (a) to (c) being repeated until a minimum value of the disturbance-information-specific sum error information (ε_{min}) is determined, and the correction information (ici_{opt}) has been derived from this [- claim 7]. Determination of correction information (ici_{opt}) using the iterative search represents a highly stable method.

[0016] According to a further advantageous refinement of the method according to the invention, the additionally deliberately disturbed received symbols are in each case corrected by equalization as a function of frequency-selective transmission characteristics of the transmission medium before the comparison with the respective closest modulation-specific modulation symbol [- claim 8]. Equalizing the received multicarrier signal to correct for the frequency-selective transmission characteristics of the transmission medium means that any errors which may have occurred in the comparison of the deliberately disturbed received symbols with the respective closest modulation-specific modulation symbols are minimized, and the quality of the determined correction information is thus improved.

[0017] Advantageously, once steps (a) to (d) have each been carried out for each reference disturbance information item the received symbols of the subcarriers which are each [arranged] further away from at least some of the subcarriers in the frequency domain are each subjected to disturbances from the reference disturbance information, and the disturbed received symbols are then additively superimposed as deliberate test disturbances on the received symbol of the additionally disturbed subcarrier (a'). Steps (b) to (d) are then carried out [- claim 9]. Giving additional consideration to those subcarrier-specific disturbances which are in each case caused by adjacent carriers that are further away in the frequency domain further improves the quality of the determined correction information.

[0018] In order to achieve a further improvement in the process of establishing the correction information, according to a further advantageous refinement of the method according to the invention, the received symbols which have been corrected using the correction information are demodulated. Errors are identified in the demodulated received symbols using error identification information inserted into the transmitted information, and identified, erroneous received symbols are corrected. When errors are identified, steps (b) to (d) are carried out once again, with the corrected received symbols being used for determining the correction information [- claim 10].

[0019] Further advantageous refinements of the method and system according to the invention[, as well as the use of the method according to the invention and a receiving arrangement] for receiving a multicarrier signal having a number of frequency-discrete subcarriers [can be found in the further claims] are described below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] The method according to the invention will be explained in more detail in the following text with reference to four drawings, in which:

Figure 1 [shows] is graph of a disturbance model on which the method according to the invention is based, which is used to illustrate the mutual subcarrier-specific interference between subcarriers in a multicarrier signal which are [arranged] adjacent in the frequency domain,

Figure 2 [shows] is a block diagram of a circuit [arrangement] using the method according to the invention,

Figure 3 [shows] is a block diagram of an advantageous refinement of a circuit [arrangement] for additive superimposition of reference disturbance information, and test disturbances derived from it, on the respective subcarriers in a received multicarrier signal, and

Figure 4 [shows an illustration, in the form of] is a graph[,] of an error curve or correction function from which the correction information to minimize the subcarrier-specific disturbances in a received multicarrier signal is derived.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0021] Figure 1 [shows] is graph of a disturbance model, [arranged] in the frequency domain, to illustrate the problem on which the method according to the invention is based. The disturbance model shows, in detail form, a number of subcarriers st_{i-1}, st_i, st_{i+1} in a multicarrier signal ms which has, in particular, n subcarriers st1...n and is formed using a multicarrier method. It is assumed in the following text that the multicarrier signal is produced using an OFDM transmission method. Originating from each subcarrier st_i, subcarrier-specific disturbances icix are produced in those subcarriers st_{i-1} and st_{i+1} which are [arranged] adjacent in the frequency domain, and these disturbances are indicated by small arrows in the disturbance model. Conversely, the centrally arranged i-th subcarrier st_i is influenced by the subcarrier-specific disturbances - indicated by $icix_{-1}$ and $icix_{+1}$ in [figure] Fig. 1 - caused by the two adjacent subcarriers st_{i-1} and st_{i+1}, with the respective i-th subcarrier st_i in each case having the subcarrier-specific disturbances $icix_{-1}$, $icix_{+1}$ which are produced actively superimposed on it. As shown in [Figure] Fig. 1, the received multicarrier signal ms is a complicated superimposition of a very large number of signal elements, so that it is no longer possible to establish directly the subcarrier-specific disturbances icix originating from the individual subcarriers st1...n.

[0022] Figure 2 [shows, in the form of] is a block diagram[,] of a circuit [arrangement which is arranged] in a receiving unit E and by [means of] which the subcarrier-specific disturbances icix - also referred to as ICI disturbances in the following text - contained in the received OFDM signal ms are estimated, with the received OFDM signal ms then being corrected by equalization as a function of the estimation result. The block diagram shows a receiving unit E which has a receiving antenna A and may, for example, be a modular component in base stations or network termination units, which act as receiving systems in wireless communications networks. A radio-frequency converter unit HFU is connected via an input EH to the receiving antenna A which is fitted externally on the receiving unit E. A local oscillator

LO [is arranged] in the radio-frequency converter unit HFU[, and] has oscillator-specific phase noise φ_{LO}. The radio-frequency converter HFU is connected via an output AH to an input EW of a converter unit WAS. The converter unit WAS [has means for] performs analog/digital conversion and [for] subsequent serial/parallel conversion (A/D, S/P) of an incoming received signal ms'. The converter unit WAS has n outputs AW1...n, which are connected to corresponding inputs EF1...n of a transformation unit FFT for carrying out a discrete "Fast Fourier Transformation". The transformation unit FFT is connected via n outputs AF1...n to corresponding inputs EP1...n of a parallel/serial converter PSW.

[0023] The parallel serial converter PSW is connected via an output AP to one input ER of each of four parallel-arranged reference modules RM1...4, by [means of] which four defined disturbance signals, or reference disturbance information items ici1...4 representing them, are added to the received OFDM signal ms. To do this, each of the four reference modules RM1...4 has a disturbance unit STE, each of which is associated with one of the reference disturbance information items ici1...4, and by [means of] which the individual subcarriers st1...n in the received OFDM signal ms have the respectively associated reference disturbance information ici1...4 additively superimposed on them. Each reference module RM1...4 also has an equalizer unit EZ for linear equalization of the received OFDM signal for the radio channel characteristics H(f), and an error detector unit FE in order to establish disturbance-information-specific sum error information $s\varepsilon 1...4$. Each error detector unit FE is connected via an output AF to an output AR of the respective reference module RM1...4. Each of the four reference modules RM1...4 is connected via the output AR to an input EA1...4 of an evaluation unit ASW.

[0024] The output AP of the parallel/serial converter PSW is also connected to an input EV of a delay unit VE, which delays the received OFDM signal ms by a predetermined time constant $\Delta\tau$. The delay unit VE is connected via an output AV to the input EK of correction unit KE. The correction unit KE has a control input SE, which is connected to a control output SA of the evaluation unit ASW. The correction unit AE is connected via an output AK to an input EE of a further equalizer unit EZ, which is connected via an output AE to an input AD of a demodulator DMOD. The demodulator DMOD has an output AD, to which the demodulated received signal is passed on as a digital data signal di.

[0025] The method according to the invention will be explained in the following text with reference to the circuit [arrangement] illustrated in [Figure] Fig. 2.

[0026] In a transmitter which is not illustrated, a multicarrier method, for example, an OFDM transmission method, is used to convert the information to be transmitted, by [means of] a phase-modulating modulation method - for example 4QAM or 16QAM - to corresponding modulation symbols, which are then converted to an OFDM signal ms, which has a number of frequency-discrete subcarriers st1...n, and this is transmitted via the "radio channel" transmission medium FK to the receiving unit E. The radio channel FK has frequency-selective transmission characteristics H(f), which distort the amplitude and phase of the OFDM signal ms. The transmitted OFDM signal ms is received via the receiving antenna A, which is [arranged] mounted externally on the receiving unit E, and is supplied to the radio-frequency converter unit HFU. The received OFDM signal ms is down-mixed to the intermediate-frequency band by the local oscillator LO[, arranged] in the radio-frequency converter unit HFU, with the phase noise φ_{LO} in the local oscillator LO producing the subcarrier-specific disturbances icix in the individual subcarriers st1...n in the received OFDM signal ms. The OFDM signal ms' which has been down-mixed to the intermediate-frequency band, is analog/digital converted by the converter unit WAS, and is then parallelized by serial/parallel conversion to corresponding n-time-discrete samples zs1...n which represent the digital OFDM signal. The discrete "Fast Fourier Transformation" that is carried out in the transformation unit FFT is used to calculate the corresponding n received symbols es1...n from the n time-discrete samples zs1...n, and these are then converted by the parallel/serial converter PSW to a serial datastream es1...n. It should be noted that the serial/parallel and parallel/serial converter illustrated in [Figure] Fig. 2 is not absolutely essential, since many modern microprocessors already process the incoming and outgoing information in serial form in order to carry out the "Fast Fourier Transformation". The received symbols es1...n which are each passed to the output AW of the parallel/serial converter PSW and represent the currently received subcarriers st1...n in the received OFDM signal ms, are each supplied to the four reference modules RM1...4.

[0027] The operation of the reference modules RM1...4 will be explained in more detail in the following text.

[0028] The disturbance units STE [which are arranged] in the reference modules RM1...4 are used in each case to superimpose reference disturbance information ici1...4, which represents subcarrier-specific disturbances icix, on the transmitted received symbols es1...n. To this end, using the reference disturbance information ici1...4, subcarrier-specific disturbances $icix_{-1}$, $icix_{+1}$ - also referred to as defined test disturbances - are derived from the respective subcarriers st_{i-1}, st_{i+1} [arranged] adjacent [around] to an i-th subcarrier st_i, for example by multiplication by the

reference disturbance information ici1...4 - and the two derived test disturbances $icix_{-1}$, $icix_{+1}$, are then additively superimposed on the centrally arranged i-th subcarrier st_i.

[0029] By way of example, [Figure] Fig. 3 shows a circuitry embodiment of the disturbance unit STE for forming the test disturbances icix and for additively superimposing the test disturbances icix that are formed on the subcarriers st1...n. The disturbance unit STE has three timers T1...3, which are used to delay the received symbols es1...n, which arrive in serial form and represent the individual subcarriers st1..n. Arranging the three timers T1...3 in series means that three subcarriers st_{i-1}, st_i and st_{i+1}, which are [arranged] adjacent in the frequency domain and are represented by the received symbols es1...n, are in each case available at the same time. The first and the third timer T1, T3 are each connected via an output AT to an input EM of a multiplier M, which is used to multiply the respective received symbol es1...n currently stored in the corresponding timer T1, T3 by the reference disturbance information ici1...4 associated with the respective reference module RM1...4. The two multipliers M are connected via in each case one output AM to inputs EA of an adder ADD, to which an output AT of the second timer T2 is also connected. The circuit [arrangement] illustrated in [Figure] Fig. 3 is used to multiply the respective subcarriers st_{i-1}, st_{i+1}, which are [arranged] adjacent about an i-th subcarrier, or the received symbols es1...n representing them by the respectively associated reference disturbance information ici1...4, and the two multiplication products which each represent test disturbances $icix_{-1}$, $icix_{+1}$ added to the i-th subcarrier st_i, or to the received symbol es1...n representing it. Depending on the respective mathematical sign of the individual reference disturbance information items ici1...4, the test disturbances $icix_{-1}$, $icix_{+1}$ which are formed are added to or subtracted from the respective i-th subcarrier st_i, which the disturbance process which is illustrated in [Figure] Fig. 1, based on the phase noise φ_{LO} of the local oscillator LO[, arranged] in the radio-frequency converter unit HFU[,] being reversed by the subtraction of a test disturbance icix.

[0030] In order to allow the ICI disturbances ici0 caused by the phase noise in the oscillator LO to be established or estimated accurately, the received symbols es'1...n to which the various reference disturbance information items ici1...4 have been applied are also linearly equalized by the equalizer unit EZ. In order to allow linear equalization to correct for the transmission characteristics of the transmission medium, the transfer function H(f) of the radio channel FK is established, for example using pilot symbols. The received symbols es'1...n are then multiplied by the inverse transfer function 1/H(f). The equalized received symbols es"1...n are then supplied to the error detector unit FE.

[0031] In the error detection unit FE, the received symbols es"1...n supplied to it are each compared with the next-best or most probable modulation symbol - the set of modulation symbols is in each case dependent on the modulation method used - and the subcarrier-specific error information item $\Delta\varepsilon1..n$ is formed for each received symbol es"1...n representing the difference or the interval between the received symbol es"1...n and the next-best modulation symbol. The subcarrier-specific error information items $\Delta\varepsilon1..n$ determined for each reference disturbance information item ici1...4 over all the subcarriers st1...n are then added to form a disturbance-information-specific sum error information item $s\varepsilon1...4$, where $s\varepsilon1...4 = \sum|\Delta\varepsilon1...n|$. The four disturbance-information-specific sum error information items $s\varepsilon1...4$ defined in the four reference modules RM1...4 are each passed on to the evaluation unit ASW.

[0032] In the evaluation unit ASW, correction information ici_{opt} is derived, in accordance with the error curve illustrated in [Figure] Fig. 4, from the four predetermined reference disturbance information items ici1...4 and from the four disturbance-information-specific sum error information items $s\varepsilon1...4$ defined in the four reference modules RM1...4. The error curve at the same time represents a correction function and is illustrated in a two-dimensional coordinate system, with the reference disturbances ici1...4, or the test disturbances icix derived from them, being plotted on the abscissa, and the respectively defined, disturbance-information-specific sum error information items $s\varepsilon1...4$ being shown on the ordinate - where $s\varepsilon1...4 = \sum|\Delta\varepsilon1...n(ici1...4)|$. For the exemplary embodiment it is assumed that the sums of the respective subcarrier-specific error information items $\Delta\varepsilon1...n$, that is to say the disturbance-information-specific sum error information items $s\varepsilon1...4 = \sum|\Delta\varepsilon1...n|$, rise linearly as the ICI interference increases, that is to say as the magnitudes of the reference disturbance information items ici1...4 rise, since the disturbance model illustrated in [Figure] Fig. 1 is based on additive disturbance terms. Ideally, when a multicarrier signal ms is received without any ICI interference, the sum of the subcarrier-specific error information items $\Delta\varepsilon1...n$ has a minimum value $s\varepsilon_{min}$ with the minimum value $s\varepsilon_{min}$ turning to zero in an ideal communications system, without any additively superimposed Gaussian noise - AWGN - and without any estimation error $\Delta H(f)$ for the radio channel FK. In real systems, the minimum value $s\varepsilon_{min}$ has a value that is not equal to zero. Due to the phase noise from the local oscillator LO [arranged on] in the radio-frequency-converter unit HFU, the received symbols es1...n which are produced at the output of the parallel/serial converter PSW have ICI interference which cannot be recorded precisely, and which is represented by the value ici0 in [Figure] Fig. 4. Based on this ICI interference ici0,

which cannot be measured, this results in subcarrier-specific error information $\Delta\varepsilon 1 \ldots n$, whose sum $\sum|\Delta\varepsilon 1 \ldots n|$ gives the value $s\varepsilon 0$, which is likewise shown in [Figure] Fig. 4, where $s\varepsilon 0 \geq s\varepsilon_{min}$.

[0033] Figure 4 shows the intersection of the ICI interference ici0 which is contained in the received symbols es1...n but cannot be established with any great accuracy, and the sum, resulting from this, of the subcarrier-specific error information $s\varepsilon 0 = \sum|\Delta\varepsilon 1 \ldots n(ici0)|$ by a point AP. Starting from this point, or this point of origin AP, the received symbols es1...n each have the four different reference disturbance information items ici1...4 or test disturbances icix applied to them in the described manner according to the invention - in the respective reference modules RM1...4- and the disturbance-information-specific sum error information items $s\varepsilon 1 \ldots 4$ are then determined. As shown in [Figure] Fig. 4, the first and the third reference disturbance information items ici1,3 each represent a very low level of ICI interference in each case with the opposite mathematical sign, while the second and the fourth reference disturbance information items ici2,4 each represent a relatively high ICI interference level. A linear relationship is assumed between the reference disturbance information ici1...4, or the disturbance signals icix derived from them, and the disturbance-information-specific sum error information items $s\varepsilon 1 \ldots 4$ resulting from them. The linear relationship is indicated in the error curve or correction function illustrated in [Figure] Fig. 4 by [means of] a linear characteristic $\sum|\Delta\varepsilon 1 \ldots n|$ whose gradient is S. By calculating the gradient S of the correction function, it is possible to establish from the known output variables - in this case from the reference disturbance information items ici1...4 - and the disturbance-information-specific sum error information items $s\varepsilon 1 \ldots 4$ established with the aid of the reference modules RM1...4, that correction information item ici_{opt} which gives the sum of the subcarrier-specific error information items $\sum|\Delta\varepsilon 1 \ldots n(ici_{opt})|$ the minimum value $s\varepsilon_{min}$; that is to say the specific correction information item ici_{opt} can be used to produce that disturbance icix which minimizes the ICI interference present in the received OFDM signal.

[0034] The correction information can be derived from the known variables using the following calculation rule:

$$s\varepsilon_0 = \frac{(s\varepsilon 1 + s\varepsilon 3)}{2} \quad (1)$$

$$\Delta s\varepsilon = \frac{(s\varepsilon 1 - s\varepsilon 3)}{2} \quad (2)$$

$$S = \frac{\Delta s\varepsilon}{ici3} = \frac{s\varepsilon 1 - s\varepsilon 3}{ici1 - ici3} \quad (3)$$

$$s\varepsilon_{min} = s\varepsilon_0 + S \bullet ici_{opt} \quad (4)$$

$$s\varepsilon 4 = \varepsilon_{min} - S \bullet (ici4 - ici_{opt}) \quad (5)$$

It follows from equations (1) to (5) that:

$$ici_{opt} = \left(\frac{s\varepsilon 4 - s\varepsilon 0}{2(s\varepsilon 1 - s\varepsilon 3)}\right) \bullet (ici1 - ici3) + \frac{ici4}{2} \quad (6)$$

$$ici_{opt} = \left(\frac{s\varepsilon 4 - \frac{(s\varepsilon 1 + s\varepsilon 3)}{2}}{2(s\varepsilon 1 - s\varepsilon 3)}\right) \bullet (ici1 - ici3) + \frac{ici4}{2} \quad (7)$$

where $ici1, ici2 \geq 0$

$ici3, ici4 \leq 0$

[0035] If the point of origin AP (ici0, sε0) is in the left-hand section of the error curve or correction function $\sum|\Delta\varepsilon 1 \ldots n|$, or in the second quadrant of the coordinate system, the calculation rule shown above must be adapted appropriately. The effort for calculating the correction information ici_{opt} is negligible since it is calculated only once after receiving an OFDM signal - after establishing the received symbols es1...n.

[0036] The calculated correction information ici_{opt} is passed on to the correction unit KE. The received OFDM signal ms and the received symbols es1...n produced at the output of the parallel/serial converter PSW are delayed in the delay unit VE by the time constant $\Delta\tau$, with the magnitude of the time constant $\Delta\tau$ being such that the received symbols es1...n are not transmitted to the correction unit KE until the correction information ici_{opt} has been calculated and passed on to the correction unit KE. In the correction unit KE, the delayed received symbols ves1...n have the optimized disturbance icix additively superimposed on them, and are

thus corrected, in the manner already described. The corrected received symbols ves'1...n are then multiplied in the equalizer unit EZ by the inverse of the transfer function 1/H(f) of the radio channel FK, and are passed on to the demodulator DMOD. In the demodulator DMOD, the equalized received symbols ves"1...n are demodulated, and are converted to a digital datastream di.

[0037] If the ICI interference level in the received OFDM signal is very high, then, according to one advantageous development of the method according to the invention, the ICI interference caused between subcarriers that are further away - for example between the subcarriers st_{i-2}, st_i and st_{i+2} is also corrected by equalization. An interactive method could be used for this purpose, in which, in a first step, those subcarriers which are [arranged] immediately adjacent in the frequency domain - in this case the subcarriers st_{i-1}, st_i and st_{i+1} - are corrected by equalization in the described manner. In a second step in the same method, the ICI interference caused by those subcarriers which are [arranged] further away in the frequency domain - in this case the subcarriers st_{i-2}, st_i and st_{i+2} - is corrected by equalization. If necessary, the iteration method can also be extended to subcarriers st_{i-b}, st_i and st_{i+b}, where b > 1, which are [arranged] further away in the frequency domain.

[0038] Furthermore, if the ICI interference level is very high, the received symbols es1...n may have very large symbol errors. When these received symbols es1...n which are subject to errors are compared with the respectively next-best modulation symbol representing the nominal value - also referred to as the estimated value - the received symbols es1...n may be compared with the wrong modulation symbol, which would lead to considerable errors in the calculation of the sum of the carrier-specific error information items $\sum|\Delta\varepsilon 1...n|$. Incorrect correction information ici_{opt} would be derived from the incorrectly determined disturbance-information-specific sum error information items $s\varepsilon 1...4 = \sum|\Delta\varepsilon 1...n|$. In the worst case, this would cause an increase in the bit errors in the demodulated datastream di.

[0039] According to a further advantageous refinement of the method according to the invention - not illustrated - an error handling routine - also referred to as Forward Error Correction, FEC - is provided, which is used to investigate the demodulated datastream di for any bit errors which may have occurred. According to this advantageous refinement of the method according to the invention, an additional interaction method is carried out when big errors are identified, in which incorrectly identified received symbols are corrected and the sum of the carrier-specific error information items $\sum|\Delta\varepsilon 1...n|$ is formed once again using the corrected received symbols. This

embodiment variant can be used in particular for modulation methods having a relatively large number of stages.

[0040] According to one further refinement variant of the method according to the invention, only some of the received symbols es1...n derived from the received multicarrier signal ms are used for establishing the correction information ici_{opt}, thus minimizing the complexity for calculating the correction information ici_{opt}, and hence minimizing the delay to the received multicarrier signal ms, that is to say the delay constant $\Delta\tau$.

[0041] According to one advantageous development, the method according to the invention is used together with an error handling routine. In this case, no equalization of the ICI interference in the received multicarrier signal is carried out initially. In a first step, the received multicarrier signal is first of all demodulated, and the demodulated datastream di is then investigated for bit errors, using the error handling routine. Only if bit errors that are identified can no longer be corrected is the method according to the invention carried out, with bit errors that have been identified, that is to say incorrect received symbols es1...n, not being included in the formation of the disturbance-information-specific sum error information items $s\varepsilon 1...4 = \sum|\Delta\varepsilon 1...n|$. This may be done, for example, by masking out the incorrect subcarriers st1...n or received symbols es1...n or by appropriate correction of the faulty received symbols es1...n. This advantageous development can be repeated iteratively until all the ICI interference has been corrected by equalization.

[0042] According to one alternative refinement variant of the method according to the invention, based on the error curve illustrated in [Figure] Fig. 4, the minimum sum ε_{min} of the subcarrier-specific error information items $\sum|\Delta\varepsilon 1...n|$ is determined by [means of] an iterative search - with a defined step width - using two small reference disturbance information items ici1, 3 or test disturbances.

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Description

Method, use of the method and a receiving arrangement for receiving multicarrier signals having a number of frequency-discrete subcarriers

In wireless communications networks, based on radio channels, in particular in point-to-multipoint radio feeder networks - also referred to as "Radio In The Local Loop" or "RLL" - a number of network termination units are each connected via one or more radio channels to a base station - also referred to as "Radio Base Station" or "RBS". For example, a wireless feeder network for wireless voice and data communication is described on pages 36, 37 of telecom report No. 18 (1995), Issue 1 "Drahtlos zum Freizeichen" [Wireless for calling]. The described communications system is an RLL subscriber access in conjunction with a modern broadband infrastructure - for example "Fiber to the curb" - which can be implemented in a short time and without major effort, instead of laying wire-based connecting cables. The network termination units RNT associated with the individual subscribers are connected via the "radio channel" transmission medium and the base station RBS to a higher-level communications network, for example to the ISDN-oriented landline network.

The increasingly widespread use of multimedia applications means that high-bit-rate data streams have to be transmitted quickly and reliably via communications networks, in particular via wireless communications networks and via mobile radio systems, with the radio transmission systems, which are based on a "radio channel" transmission medium which is susceptible to disturbances and whose transmission

quality is difficult to assess, being subject to stringent requirements. One transmission method for transmitting broadband data streams - for example video data streams - is, for example, the OFDM transmission method which is based on a multicarrier method - also referred to as Orthogonal Frequency Division Multiplexing

OFDM. In the OFDM transmission technique, the information to be transmitted or the data stream to be transmitted is subdivided or parallelized between a number of subchannels or subcarriers within the radio channel, with the information to be transmitted in each case being transmitted at a relatively low data rate, but in parallel in an additively superimposed form. The OFDM transmission technique is used, for example, for digital terrestrial broadcast radio - also referred to as Digital Audio Broadcasting DAB - and for digital terrestrial television - also referred to as Digital Terrestrial Video Broadcasting DTVB. In particular, the OFDM transmission technique is intended to be used in future wireless local communications networks - also referred to as Wireless LAN or WLAN - and in future mobile radio communications networks - for example UMTS. The OFDM transmission technique will also be used in future access methods such as MC-SSMA - Multi-Carrier Spread Spectrum Multiple Access - or MC-CDMA - Multi-Carrier CDMA.

The OFDM transmission method is described in more detail in Figure 6 on page 46 of the document "Mitteilungen der TU-Braunschweig, Mobilfunktechnik für Multimedia-Anwendungen" [Reports from Brunswick Technical University, Mobile Radio Technology for Multimedia Applications], Professor H. Rohling, Year XXXI, Issue 1-1996. In this case, based on a serial datastream in the transmitter, serial/parallel conversion is carried out for modulation of the, for example, n subcarriers, with a binary code word with a word length k - the word length k is dependent on the modulation method used - being formed in each case for the i-th OFDM block in time with the block length T' and the j-th subcarrier. A transmitter-specific modulation method is used to form the corresponding complex modulation symbols - also referred to as transmission symbols in the following text - from the

code words that have been formed, with a transmission symbol being allocated to each of the k subcarriers at each time i. The separation between the individual subcarriers is defined by $\Delta f = 1-T'$, thus guaranteeing the orthogonality of the individual subcarrier

signals in the interval [0,T′] that is used. The oscillations of the individual subcarriers are multiplied by the corresponding modulation symbols or transmission symbols, and the modulation products that are formed are then added, to produce the corresponding time-discrete transmission signal for the i-th OFDM block in time. This transmission signal is calculated directly from the modulation symbols or transmission symbols of the individual subcarriers under consideration by Inverse, Discrete Fourier Transformation - IDFT. In order to minimize intersymbol interference, each OFDM block is preceded by a guard interval T_G in the time domain which results in the time-discrete OFDM signal being lengthened in the interval $[-T_G, 0]$ - see "Mitteilungen der TU-Braunschweig, Mobilfunktechnik für Multimedia-Anwendungen" [Report from Brunswick Technical University, Mobile Radio Technology for Multimedia Applications], Figure 7. The guard interval T_G that is inserted advantageously corresponds to the maximum delay time difference that occurs between the individual propagation paths which occur during radio transmission. The removal of the added guard interval T_G at the receiver end avoids, for example, any interference between the i-th OFDM block and the OFDM signal which is adjacent in time at the time i-1, so that the transmission signal is received over all the circuitous paths in the interval [0,T′], and the orthogonality is fully maintained between the subcarriers in the receiver. If there are a large number of subcarriers - for example n = 256 subcarriers - and the symbol durations $T = T' + T_G$ are correspondingly long, then the duration T_G is short in comparison to T, so that the insertion of the guard interval efficiently has no significant adverse effect on the bandwidth, and the resultant overhead is only small. After sampling of the transmission signal, received at the input of the receiver in baseband - by

an A/D converter - and after extraction of the interval being used - that is to say after removal of the guard interval T_G - a Discrete Fourier Transformation - DFT - is used to transform the received transmission signal to the frequency domain, that is to say the received modulation symbols and the received symbols are established. A suitable demodulation method

is used to produce the corresponding received code words from the established received symbols and the received serial datastream is formed by parallel/serial conversion from these code words. The avoidance of intersymbol interference when using OFDM transmission methods considerably reduces the computation effort in the respective receiver, as a result of which the OFDM transmission technique is used, for example, for terrestrial transmission of digital television signals - for example for transmission of broadband datastreams at a transmission rate of 34 Mbps per radio channel.

Absolute or differential modulation methods and corresponding coherent or incoherent demodulation methods are used for transmission of the serial datastream to be transmitted using the OFDM transmission method. Examples of an absolute modulation method include 4-QAM or 16-QAM - Quadrature Amplitude Modulation. Although the orthogonality of the subcarriers is fully maintained when the OFDM transmission method is used to transmit the transmission signal that has been formed via the only "radio channel" transmission medium, the transmission characteristics of the radio channel result in the transmitted, frequency-discrete or frequency-selective transmission symbols being varied both in phase and amplitude. The amplitude and phase influence of the radio channel affects the individual subcarriers, which each have a very narrow bandwidth, on a subcarrier-specific basis; furthermore, noise signals are additively superimposed on the transmitted user signal. When using coherent demodulation methods, channel estimation is required which, depending on the quality requirements, involves a considerable technical and financial implementation penalty and, furthermore, reduces the performance of the transmission system. It is advantageous to use differential modulation methods and corresponding incoherent demodulation methods in

which there is no need for complex radio channel estimation. In differential modulation methods

the information to be transmitted is not transmitted directly by selection of the modulation symbols or of the frequency-discrete transmission symbols, but by changing the frequency-discrete transmission symbols, which are adjacent in time, on the same subcarrier. Examples of differential modulation methods include 64-step 64-DPSK - Differential Phase Shift Keying - and 64-DAPSK - Differential Amplitude and Phase Shift Keying. In 64-DAPSK, both the amplitude and the phase are differentially modulated at the same time.

If there are major delay time differences between the individual signal paths, that is to say when severe multi-path propagation occurs, different attenuation levels, dependent on the transmission channel, with attenuation differences of up to 20 dB or more, may occur between the individual received subcarriers. The received subcarriers having high attenuation levels, or subcarriers with low S/N ratios - also referred to as the signal power-to-noise power ratio - have a very high symbol error rate, as a result of which the overall bit error rate over all the subcarriers rises considerably. In the case of subcarriers modulated using coherent modulation methods, it is already known for the attenuation losses caused by the frequency-selective transmission characteristics of the transmission medium - also referred to as the transfer function H(f) - to be corrected at the receiving end by using the inverse transfer function - also referred to as 1/H(f), with the frequency-selective attenuation losses being determined, for example, by evaluating transmitted reference pilot tones, which are each associated with specific subcarriers.

Normally, OFDM signals arriving at a receiver are mixed down to the intermediate frequency band or baseband by means of a local oscillator arranged in a radio-frequency unit - also referred to as an RF frontend.

The respective local oscillators arranged at the transmitting end and at the receiving end, have different frequency fluctuations and different phase noise depending

on the quality and the Q factor. OFDM signals in particular are highly susceptible to frequency fluctuations and phase noise, which are produced in particular in low-cost LO oscillators, so they result in loss of the orthogonality between the subcarriers arranged adjacent in the frequency domain. The phase noise from a local oscillator causes disturbances in the demodulated baseband signal resulting, in particular, in the production of a Common Phase Error - also referred to as CPE interference or disturbances - and "Inter Carrier Interference" - also referred to as ICI disturbances in the baseband signal.
CPE disturbances rotate all the subcarriers in an OFDM received signal through a constant phase difference, in which case the phase difference can be estimated, and the OFDM signal can be corrected accordingly, with minimal effort. On the other hand, ICI disturbances cause mutual interference between the subcarriers arranged adjacent in the frequency domain, with the respective extent of such disturbances being dependent on the nature of the information being transmitted. ICI disturbances are produced in the convolution of the individual subcarriers with the local oscillator carrier signal, which is subject to phase noise. If the same information is transmitted on each subcarrier, the same ICI interference is additively superimposed on each subcarrier. During normal operation, each subcarrier is subject to different amplitude fluctuations, which result in different ICI disturbances being produced in the individual subcarriers, depending on the modulation method being used and on the data being transmitted. The received OFDM signal is a complicated additive superimposition of a very large number of signal elements, so that the ICI interference can be established directly only by increased effort.

Oscillators with low phase noise - also referred to as

pure phase oscillators - are available, but these are either very expensive or have a minimal trimming range, and which thus require complex additional baseband circuits.

The invention is based on the object of designing a low-cost means of transmitting information using a multicarrier method and, in particular, of achieving effective utilization of the transmission resources available in the transmission medium. Based on a method and a receiving arrangement according to the features of the precharacterizing clauses of patent claims 1 and 15, the object is achieved by the characterizing features of these claims.

In the method according to the invention for receiving a multicarrier signal having a number of frequency-discrete subcarriers, the information to be transmitted is converted by means of a multicarrier method to frequency-discrete modulation symbols, and is inserted into the multicarrier signal. The individual frequency-discrete subcarriers of the multicarrier signal transmitted via a transmitter medium are each subject to subcarrier-specific disturbances caused by subcarriers arranged adjacent in the frequency domain. The major aspect of the method according to the invention is that the subcarriers in the received multicarrier signal are additionally deliberately subjected to disturbances, and that correction information which represents subcarrier-specific disturbances is derived from the subcarriers which have been additionally deliberately subjected to disturbances. The received, frequency-discrete subcarriers are then corrected in accordance with the determined correction information.

The major advantage of the method according to the invention is that the compensation according to the invention for the subcarrier-specific disturbances or ICI disturbances contained in the received multicarrier signal means that particularly low-cost local oscillators can be used in the respective transmitting and receiving devices. Such oscillators may, for

example, be based on gallium arsenide and can be produced with the minimum financial cost and technical complexity using MMIC. Furthermore, no additional insertion of redundant information is required at the transmission end for estimation

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of the ICI disturbances or to establish correction information in order to implement the method according to the invention, thus allowing effective utilization of the transmission resources available in the transmission medium to be achieved.

The received symbols which represent frequency-discrete subcarriers are advantageously derived from the received multicarrier signal. In this advantageous refinement, k differently defined reference disturbance information items are provided, in which case, for each reference disturbance information item, the received symbols in the subcarriers which are in each case arranged adjacent around at least some of the subcarriers in the frequency domain are each subjected to disturbances from the reference disturbance information, and the disturbed received symbols in the adjacent subcarriers are then additively superimposed (a) as deliberate test disturbances on the received symbol in the additionally disturbed subcarrier. The additionally deliberately disturbed received symbols are each compared with the closest modulation-specific modulation symbol, and subcarrier-specific error information is formed (b) as a function of the comparison results, and disturbance-information-specific sum error information is formed (c) from the subcarrier-specific error information. The k reference disturbance information items and the k sum error information items are then used to derive (d) the correction information - claim 3. This advantageous refinement allows the correction information for estimating the ICI disturbances to be established very accurately, since the correction information has been derived by averaging over all the subcarriers in the received multicarrier signal.

According to one advantageous refinement of the method

according to the invention, the correction information (ici_{opt}) is determined in the course of an iterative search, with the k reference disturbance information items (ici1...4) being established in the course of the iterative search, and steps (a) to (c) being repeated until a minimum value of the disturbance-information-specific

sum error information (ε_{min}) is determined, and the correction information (ici_{opt}) has been derived from this - claim 7. Determination of correction information (ici_{opt}) using the iterative search represents a highly stable method.

According to a further advantageous refinement of the method according to the invention, the additionally deliberately disturbed received symbols are in each case corrected by equalization as a function of frequency-selective transmission characteristics of the transmission medium before the comparison with the respective closest modulation-specific modulation symbol - claim 8. Equalizing the received multicarrier signal to correct for the frequency-selective transmission characteristics of the transmission medium means that any errors which may have occurred in the comparison of the deliberately disturbed received symbols with the respective closest modulation-specific modulation symbols are minimized, and the quality of the determined correction information is thus improved.

Advantageously, once steps (a) to (d) have each been carried out for each reference disturbance information item the received symbols of the subcarriers which are each arranged further away from at least some of the subcarriers in the frequency domain are each subjected to disturbances from the reference disturbance information, and the disturbed received symbols are then additively superimposed as deliberate test disturbances on the received symbol of the additionally disturbed subcarrier (a'). Steps (b) to (d) are then carried out - claim 9. Giving additional consideration to those subcarrier-specific disturbances which are in each case caused by adjacent carriers that are further away in the frequency domain further improves the quality of the determined correction information.

In order to achieve a further improvement in the process of establishing the correction information, according to a further advantageous refinement of the method according to the invention, the received symbols which have been corrected using the correction information are

demodulated. Errors are identified in the demodulated received symbols using error identification information inserted into the transmitted information, and identified, erroneous received symbols are corrected. When errors are identified, steps (b) to (d) are carried out once again, with the corrected received symbols being used for determining the correction information - claim 10.

Further advantageous refinements of the method according to the invention, as well as the use of the method according to the invention and a receiving arrangement for receiving a multicarrier signal having a number of frequency-discrete subcarriers can be found in the further claims.

The method according to the invention will be explained in more detail in the following text with reference to four drawings, in which:

Figure 1 shows a disturbance model on which the method according to the invention is based, which is used to illustrate the mutual subcarrier-specific interference between subcarriers in a multicarrier signal which are arranged adjacent in the frequency domain,

Figure 2 shows a circuit arrangement using the method according to the invention,

Figure 3 shows an advantageous refinement of a circuit arrangement for additive superimposition of reference disturbance information, and test disturbances derived from it, on the respective subcarriers in a received multicarrier signal, and

Figure 4 shows an illustration, in the form of a graph, of an error curve or correction function from which the correction information to minimize the subcarrier-

specific disturbances in a received multicarrier signal is derived.

Figure 1 shows a disturbance model, arranged in the frequency domain, to illustrate the problem on which the method according to the invention

is based. The disturbance model shows, in detail form, a number of subcarriers st_{i-1}, st_i, st_{i+1} in a multicarrier signal ms which has, in particular, n subcarriers st1...n and is formed using a multicarrier method. It is assumed in the following text that the multicarrier signal is produced using an OFDM transmission method. Originating from each subcarrier st_i, subcarrier-specific disturbances icix are produced in those subcarriers st_{i-1} and st_{i+1} which are arranged adjacent in the frequency domain, and these disturbances are indicated by small arrows in the disturbance model. Conversely, the centrally arranged i-th subcarrier st_i is influenced by the subcarrier-specific disturbances - indicated by $icix_{-1}$ and $icix_{+1}$ in figure 1 - caused by the two adjacent subcarriers st_{i-1} and st_{i+1}, with the respective i-th subcarrier st_i in each case having the subcarrier-specific disturbances $icix_{-1}$, $icix_{+1}$ which are produced actively superimposed on it. As shown in Figure 1, the received multicarrier signal ms is a complicated superimposition of a very large number of signal elements, so that it is no longer possible to establish directly the subcarrier-specific disturbances icix originating from the individual subcarriers st1...n.

Figure 2 shows, in the form of a block diagram, a circuit arrangement which is arranged in a receiving unit E and by means of which the subcarrier-specific disturbances icix - also referred to as ICI disturbances in the following text - contained in the received OFDM signal ms are estimated, with the received OFDM signal ms then being corrected by equalization as a function of the estimation result. The block diagram shows a receiving unit E which has a receiving antenna A and may, for example, be a modular component in base stations or network termination units, which act as receiving systems in wire-less communications networks. A radio-frequency converter

unit HFU is connected via an input EH to the receiving antenna A which is fitted externally on the receiving unit E. A local oscillator LO is arranged in the radio-frequency converter unit HFU, and has oscillator-specific phase noise φ_{LO}. The radio-frequency converter HFU is connected via an output AH

to an input EW of a converter unit WAS. The converter unit WAS has means for analog/digital conversion and for subsequent serial/parallel conversion (A/D, S/P) of an incoming received signal ms'. The converter unit WAS has n outputs AW1...n, which are connected to corresponding inputs EF1...n of a transformation unit FFT for carrying out a discrete "Fast Fourier Transformation". The transformation unit FFT is connected via n outputs AF1...n to corresponding inputs EP1...n of a parallel/serial converter PSW.

The parallel serial converter PSW is connected via an output AP to one input ER of each of four parallel-arranged reference modules RM1...4, by means of which four defined disturbance signals, or reference disturbance information items ici1...4 representing them, are added to the received OFDM signal ms. To do this, each of the four reference modules RM1...4 has a disturbance unit STE, each of which is associated with one of the reference disturbance information items ici1...4, and by means of which the individual subcarriers st1...n in the received OFDM signal ms have the respectively associated reference disturbance information ici1...4 additively superimposed on them. Each reference module RM1...4 also has an equalizer unit EZ for linear equalization of the received OFDM signal for the radio channel characteristics H(f), and an error detector unit FE in order to establish disturbance-information-specific sum error information sε1...4. Each error detector unit FE is connected via an output AF to an output AR of the respective reference module RM1...4. Each of the four reference modules RM1...4 is connected via the output AR to an input EA1...4 of an evaluation unit ASW.

The output AP of the parallel/serial converter PSW is also connected to an input EV of a delay unit VE, which

delays the received OFDM signal ms by a predetermined time constant $\Delta\tau$. The delay unit VE

is connected via an output AV to the input EK of correction unit KE. The correction unit KE has a control input SE, which is connected to a control output SA of the evaluation unit ASW. The correction unit AE is connected via an output AK to an input EE of a further equalizer unit EZ, which is connected via an output AE to an input AD of a demodulator DMOD. The demodulator DMOD has an output AD, to which the demodulated received signal is passed on as a digital data signal di.

The method according to the invention will be explained in the following text with reference to the circuit arrangement illustrated in Figure 2.

In a transmitter which is not illustrated, a multicarrier method, for example, an OFDM transmission method, is used to convert the information to be transmitted, by means of a phase-modulating modulation method - for example 4QAM or 16QAM - to corresponding modulation symbols, which are then converted to an OFDM signal ms, which has a number of frequency-discrete subcarriers st1...n, and this is transmitted via the "radio channel" transmission medium FK to the receiving unit E. The radio channel FK has frequency-selective transmission characteristics H(f), which distort the amplitude and phase of the OFDM signal ms. The transmitted OFDM signal ms is received via the receiving antenna A, which is arranged externally on the receiving unit E, and is supplied to the radio-frequency converter unit HFU. The received OFDM signal ms is down-mixed to the intermediate-frequency band by the local oscillator LO, arranged in the radio-frequency converter unit HFU, with the phase noise φ_{LO} in the local oscillator LO producing the subcarrier-specific disturbances icix in the individual subcarriers st1...n in the received OFDM signal ms. The

OFDM signal ms' which has been down-mixed to the intermediate-frequency band, is analog/digital converted by the converter unit WAS, and is then parallelized by serial/parallel conversion to corresponding n-time-discrete samples zs1...n

which represent the digital OFDM signal. The discrete "Fast Fourier Transformation" that is carried out in the transformation unit FFT is used to calculate the corresponding n received symbols es1...n from the n time-discrete samples zs1...n, and these are then converted by the parallel/serial converter PSW to a serial datastream es1...n. It should be noted that the serial/parallel and parallel/serial converter illustrated in Figure 2 is not absolutely essential, since many modern microprocessors already process the incoming and outgoing information in serial form in order to carry out the "Fast Fourier Transformation". The received symbols es1...n which are each passed to the output AW of the parallel/serial converter PSW and represent the currently received subcarriers st1...n in the received OFDM signal ms, are each supplied to the four reference modules RM1...4.

The operation of the reference modules RM1...4 will be explained in more detail in the following text.

The disturbance units STE which are arranged in the reference modules RM1...4 are used in each case to superimpose reference disturbance information ici1...4, which represents subcarrier-specific disturbances icix, on the transmitted received symbols es1...n. To this end, using the reference disturbance information ici1...4, subcarrier-specific disturbances $icix_{-1}$, $icix_{+1}$ - also referred to as defined test disturbances - are derived from the respective subcarriers st_{i-1}, st_{i+1} arranged adjacent around an i-th subcarrier st_i, for example by multiplication by the reference disturbance information ici1...4 - and the two derived test disturbances $icix_{-1}$, $icix_{+1}$, are then additively superimposed on the centrally arranged i-th subcarrier st_i.

By way of example, Figure 3 shows a circuitry

embodiment of the disturbance unit STE for forming the test disturbances icix and for additively superimposing the test disturbances icix that are formed on the subcarriers st1...n. The disturbance

unit STE has three timers T1...3, which are used to delay the received symbols es1...n, which arrive in serial form and represent the individual subcarriers st1..n. Arranging the three timers T1...3 in series means that three subcarriers st_{i-1}, st_i and st_{i+1}, which are arranged adjacent in the frequency domain and are represented by the received symbols es1...n, are in each case available at the same time. The first and the third timer T1, T3 are each connected via an output AT to an input EM of a multiplier M, which is used to multiply the respective received symbol es1...n currently stored in the corresponding timer T1, T3 by the reference disturbance information ici1...4 associated with the respective reference module RM1...4. The two multipliers M are connected via in each case one output AM to inputs EA of an adder ADD, to which an output AT of the second timer T2 is also connected. The circuit arrangement illustrated in Figure 3 is used to multiply the respective subcarriers st_{i-1}, st_{i+1}, which are arranged adjacent about an i-th subcarrier, or the received symbols es1...n representing them by the respectively associated reference disturbance information ici1...4, and the two multiplication products which each represent test disturbances $icix_{-1}$, $icix_{+1}$ added to the i-th subcarrier st_i, or to the received symbol es1...n representing it. Depending on the respective mathematical sign of the individual reference disturbance information items ici1...4, the test disturbances $icix_{-1}$, $icix_{+1}$ which are formed are added to or subtracted from the respective i-th subcarrier st_i, which the disturbance process which is illustrated in Figure 1, based on the phase noise φ_{LO} of the local oscillator LO, arranged in the radio-frequency converter unit HFU, being reversed by the subtraction of a test disturbance icix.

In order to allow the ICI disturbances ici0 caused by

the phase noise in the oscillator LO to be established or estimated accurately, the received symbols es'1...n to which the various reference disturbance information items ici1...4 have been applied are also linearly equalized by the equalizer

unit EZ. In order to allow linear equalization to correct for the transmission characteristics of the transmission medium, the transfer function H(f) of the radio channel FK is established, for example using pilot symbols. The received symbols es'1...n are then multiplied by the inverse transfer function 1/H(f). The equalized received symbols es''1...n are then supplied to the error detector unit FE.

In the error detection unit FE, the received symbols es''1...n supplied to it are each compared with the next-best or most probable modulation symbol - the set of modulation symbols is in each case dependent on the modulation method used - and the subcarrier-specific error information item Δε1..n is formed for each received symbol es''1...n representing the difference or the interval between the received symbol es''1...n and the next-best modulation symbol. The subcarrier-specific error information items Δε1..n determined for each reference disturbance information item ici1...4 over all the subcarriers st1...n are then added to form a disturbance-information-specific sum error information item sε1...4, where $s\varepsilon 1...4 = \sum|\Delta\varepsilon 1...n|$. The four disturbance-information-specific sum error information items sε1...4 defined in the four reference modules RM1...4 are each passed on to the evaluation unit ASW.

In the evaluation unit ASW, correction information ici_{opt} is derived, in accordance with the error curve illustrated in Figure 4, from the four predetermined reference disturbance information items ici1...4 and from the four disturbance-information-specific sum error information items sε1...4 defined in the four reference modules RM1...4. The error curve at the same time represents a correction function and is illustrated in a two-dimensional coordinate system, with the reference disturbances ici1...4, or the test

disturbances icix derived from them, being plotted on the abscissa, and the respectively defined, disturbance-information-specific sum error information items $s\varepsilon 1 \ldots 4$ being shown on the ordinate - where $s\varepsilon 1 \ldots 4 = \sum |\Delta\varepsilon 1 \ldots n(ici1 \ldots 4)|$. For the exemplary

embodiment it is assumed that the sums of the respective subcarrier-specific error information items $\Delta\varepsilon 1...n$, that is to say the disturbance-information-specific sum error information items $s\varepsilon 1...4 = \sum|\Delta\varepsilon 1...n|$, rise linearly as the ICI interference increases, that is to say as the magnitudes of the reference disturbance information items ici1...4 rise, since the disturbance model illustrated in Figure 1 is based on additive disturbance terms. Ideally, when a multicarrier signal ms is received without any ICI interference, the sum of the subcarrier-specific error information items $\Delta\varepsilon 1...n$ has a minimum value $s\varepsilon_{min}$ with the minimum value $s\varepsilon_{min}$ turning to zero in an ideal communications system, without any additively superimposed Gaussian noise - AWGN - and without any estimation error $\Delta H(f)$ for the radio channel FK. In real systems, the minimum value $s\varepsilon_{min}$ has a value that is not equal to zero. Due to the phase noise from the local oscillator LO arranged on the radio-frequency-converter unit HFU, the received symbols es1...n which are produced at the output of the parallel/serial converter PSW have ICI interference which cannot be recorded precisely, and which is represented by the value ici0 in Figure 4. Based on this ICI interference ici0, which cannot be measured, this results in subcarrier-specific error information $\Delta\varepsilon 1...n$, whose sum $\sum|\Delta\varepsilon 1...n|$ gives the value $s\varepsilon 0$, which is likewise shown in Figure 4, where $s\varepsilon 0 \geq s\varepsilon_{min}$.

Figure 4 shows the intersection of the ICI interference ici0 which is contained in the received symbols es1...n but cannot be established with any great accuracy, and the sum, resulting from this, of the subcarrier-specific error information $s\varepsilon 0 = \sum|\Delta\varepsilon 1...n(ici0)|$ by a point AP. Starting from this point, or this point of origin AP, the received symbols es1...n each have the four different reference disturbance information items ici1...4 or test disturbances icix applied to them in

the described manner according to the invention - in the respective reference modules RM1...4- and the disturbance-information-specific sum error information items sε1...4 are then determined. As shown in Figure 4, the first and the third reference disturbance information items ici1,3 each represent a very low level of ICI interference

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in each case with the opposite mathematical sign, while the second and the fourth reference disturbance information items ici2,4 each represent a relatively high ICI interference level. A linear relationship is assumed between the reference disturbance information ici1...4, or the disturbance signals icix derived from them, and the disturbance-information-specific sum error information items sε1...4 resulting from them. The linear relationship is indicated in the error curve or correction function illustrated in Figure 4 by means of a linear characteristic $\sum|\Delta\varepsilon 1...n|$ whose gradient is S. By calculating the gradient S of the correction function, it is possible to establish from the known output variables - in this case from the reference disturbance information items ici1...4 - and the disturbance-information-specific sum error information items sε1...4 established with the aid of the reference modules RM1...4, that correction information item ici_{opt} which gives the sum of the subcarrier-specific error information items $\sum|\Delta\varepsilon 1...n(ici_{opt})|$ the minimum value $s\varepsilon_{min}$; that is to say the specific correction information item ici_{opt} can be used to produce that disturbance icix which minimizes the ICI interference present in the received OFDM signal.

The correction information can be derived from the known variables using the following calculation rule:

$$s\varepsilon_0 = \frac{(s\varepsilon 1 + s\varepsilon 3)}{2} \quad (1)$$

$$\Delta s\varepsilon = \frac{(s\varepsilon 1 - s\varepsilon 3)}{2} \quad (2)$$

$$S = \frac{\Delta s\varepsilon}{ici3} = \frac{s\varepsilon 1 - s\varepsilon 3}{ici1 - ici3} \quad (3)$$

$$s\varepsilon_{min} = s\varepsilon_0 + S \bullet ici_{opt} \quad (4)$$

$$s\varepsilon 4 = \varepsilon_{min} - S \bullet \left(ici4 - ici_{opt}\right) \quad (5)$$

It follows from equations (1) to (5) that:

$$ici_{opt} = \left(\frac{s\varepsilon 4 - s\varepsilon 0}{2(s\varepsilon 1 - s\varepsilon 3)}\right) \bullet (ici1 - ici3) + \frac{ici4}{2} \qquad (6)$$

$$ici_{opt} = \left(\frac{s\varepsilon 4 - \frac{(s\varepsilon 1 + s\varepsilon 3)}{2}}{2(s\varepsilon 1 - s\varepsilon 3)} \right) \bullet (ici1 - ici3) + \frac{ici4}{2} \qquad (7)$$

where $ici1,\ ici2 \geq 0$

$ici3,\ ici4 \leq 0$

If the point of origin AP (ici0, sε0) is in the left-hand section of the error curve or correction function $\sum|\Delta\varepsilon 1...n|$, or in the second quadrant of the coordinate system, the calculation rule shown above must be adapted appropriately. The effort for calculating the correction information ici_{opt} is negligible since it is calculated only once after receiving an OFDM signal - after establishing the received symbols es1...n.

The calculated correction information ici_{opt} is passed on to the correction unit KE. The received OFDM signal ms and the received symbols es1...n produced at the output of the parallel/serial converter PSW are delayed in the delay unit VE by the time constant Δτ, with the magnitude of the time constant Δτ being such that the received symbols es1...n are not transmitted to the correction unit KE until the correction information ici_{opt} has been calculated and passed on to the correction unit KE. In the correction unit KE, the delayed received symbols ves1...n have the optimized disturbance icix additively superimposed on them, and are thus corrected, in the manner already described. The corrected received symbols ves'1...n are then multiplied in the equalizer unit EZ by the inverse of the transfer function 1/H(f) of the radio channel FK, and are passed on to the demodulator DMOD. In the demodulator DMOD, the equalized received symbols ves''1...n are demodulated, and are converted to a digital datastream di.

If the ICI interference level in the received OFDM signal is very high, then, according to one advantageous development of the method according to the invention, the ICI interference caused between subcarriers that are further away - for example between the subcarriers st_{i-2}, st_i and st_{i+2} is also corrected by equalization. An interactive method could be used for this purpose, in which, in a first step, those subcarriers which are arranged immediately adjacent in the frequency domain - in this case the subcarriers st_{i-1}, st_i and st_{i+1} - are corrected by equalization in the described manner. In a second step in the same method, the ICI interference caused by those subcarriers which are arranged further away in the frequency domain - in this case the subcarriers st_{i-2}, st_i and st_{i+2} - is corrected by equalization. If necessary, the iteration method can also be extended to subcarriers st_{i-b}, st_i and st_{i+b}, where $b > 1$, which are arranged further away in the frequency domain.

Furthermore, if the ICI interference level is very high, the received symbols es1...n may have very large symbol errors. When these received symbols es1...n which are subject to errors are compared with the respectively next-best modulation symbol representing the nominal value - also referred to as the estimated value - the received symbols es1...n may be compared with the wrong modulation symbol, which would lead to considerable errors in the calculation of the sum of the carrier-specific error information items $\sum|\Delta\varepsilon 1...n|$. Incorrect correction information ici_{opt} would be derived from the incorrectly determined disturbance-information-specific sum error information items $s\varepsilon 1...4 = \sum|\Delta\varepsilon 1...n|$. In the worst case, this would cause an increase in the bit errors in the demodulated datastream di.

According to a further advantageous refinement of the method according to the invention - not illustrated - an error handling routine - also referred to as Forward Error Correction, FEC - is provided, which is used to investigate the demodulated datastream di for any bit errors which may

have occurred. According to this advantageous refinement of the method according to the invention, an additional interaction method is carried out when big errors are identified, in which incorrectly identified received symbols are corrected and the sum of the carrier-specific error information items $\sum|\Delta\varepsilon 1...n|$ is formed once again using the corrected received symbols. This embodiment variant can be used in particular for modulation methods having a relatively large number of stages.

According to one further refinement variant of the method according to the invention, only some of the received symbols es1...n derived from the received multicarrier signal ms are used for establishing the correction information ici_{opt}, thus minimizing the complexity for calculating the correction information ici_{opt}, and hence minimizing the delay to the received multicarrier signal ms, that is to say the delay constant $\Delta\tau$.

According to one advantageous development, the method according to the invention is used together with an error handling routine. In this case, no equalization of the ICI interference in the received multicarrier signal is carried out initially. In a first step, the received multicarrier signal is first of all demodulated, and the demodulated datastream di is then investigated for bit errors, using the error handling routine. Only if bit errors that are identified can no longer be corrected is the method according to the invention carried out, with bit errors that have been identified, that is to say incorrect received symbols es1...n, not being included in the formation of the disturbance-information-specific sum error information items $s\varepsilon 1...4 = \sum|\Delta\varepsilon 1...n|$. This may be done, for example, by masking out the incorrect subcarriers st1...n or received symbols es1...n or by appropriate

correction of the faulty received symbols es1...n. This advantageous development can be repeated iteratively until all the ICI interference has been corrected by equalization.

According to one alternative refinement variant of the method according to the invention, based on the error curve illustrated in Figure 4, the minimum sum ε_{min} of the subcarrier-specific error information items $\sum|\Delta\varepsilon 1 \ldots n|$ is determined by means of an iterative search - with a defined step width - using two small reference disturbance information items ici1, 3 or test disturbances.

Patent Claims

1. A method for receiving a multicarrier signal (ms) having a number of frequency-discrete subcarriers (st1...n) and into which information is inserted which is converted by means of a multicarrier method to frequency-discrete modulation-specific modulation symbols with the individual frequency-discrete subcarriers (st1...n) of the multicarrier signal (ms) transmitted via a transmission medium (FK) each being subject to subcarrier-specific disturbances (ici0) caused by subcarriers (st1...n) arranged adjacent in the frequency domain,
characterized
   - in that the subcarriers (st1...n) of the received multicarrier signal (ms) are additionally deliberately subjected to disturbances,
   - in that correction information (ici_{opt}) which represents the subcarrier-specific disturbances (ici0) is derived from the subcarriers (st1...n) which have been additionally deliberately subjected to disturbances, and
   - in that the subcarriers (st1...n) of the received multicarrier signal (ms) are corrected in accordance with the determined correction information (ici_{opt}).

2. The method as claimed in claim 1,
characterized
in that a number of different test disturbances (icix) are provided, with the subcarriers (st1...n) being deliberately subjected to disturbances, in the event of a test disturbance

(icix), by means of constant or frequency-dependent disturbance information (ici1...4).

3. The method as claimed in claim 2, **characterized**

- in that the received symbols (es1...n) which represent frequency-discrete subcarriers (st1...n) are derived from the received multicarrier signal (ms),
- in that k differently defined reference disturbance information items (ici1...4) are provided, in which case, for each reference disturbance information item (ici1...4),

-- (a) the received symbols (es1...n) in the subcarriers (st_{i-1}, st_{i+1}) which are in each case arranged adjacent around at least some of the subcarriers (st_i) in the frequency domain are each subjected to disturbances from the reference disturbance information (ici1...4), and the disturbed received symbols in the adjacent subcarriers (st_{i-1}, st_{i+1}) are then additively superimposed as deliberate test disturbances ($icix_{-1}$, $icix_{+1}$) on the received symbol (es1...n) in the additionally disturbed subcarrier (st_i),

- (b) in that the additionally deliberately disturbed received symbols (es'1...n) are each compared with the closest modulation-specific modulation symbol, and subcarrier-specific error information (Δε1...n) is formed as a function of the comparison results, and

-- (c) disturbance-information-specific sum error information (sε1...k) is formed from the subcarrier-specific error information (Δε1...n), and

- (d) in that the correction information (ici_{opt}) is derived from the k reference disturbance information items (ici1...k) and the k sum error information items (sε1...k).

4. The method as claimed in claim 3,
characterized
- in that the frequency-discrete received symbols (es1...n) derived from the received multicarrier signal (ms) are delayed or are

temporarily stored until the correction information (ici_{opt}) has been established,

- (e) in that the delayed received symbols (ves1...n) in the subcarriers (st_{i-1}, st_{i+1}) which are in each case arranged adjacent around a subcarrier (st_i) in the frequency domain are each corrected by the determined correction information (ici_{opt}), and are then additively superimposed on the delayed received symbol (ves1...n) in the subcarrier (st_i).

5. The method as claimed in claim 3 or 4, **characterized** in that the k reference disturbance information items (ici1...k) and the k disturbance-information-specific sum error information items (sε1...k) derived from them are used to establish a correction function (KF) which is used to calculate the correction information (ici_{opt}).

6. The method as claimed in claim 5, **characterized**
   - in that four defined reference disturbance information items (ici1...4) are provided, and are used to derive the four disturbance-information-specific sum error information items (sε1...4) and
   - in that the correction information (ici_{opt}) is calculated by

$$ici_{opt}=\left(\frac{s\varepsilon 4-\frac{(s\varepsilon 1+s\varepsilon 3)}{2}}{2(s\varepsilon 1-s\varepsilon 3)}\right)\bullet(ici1-ici3)+\frac{ici4}{2}$$

   where
   sε1...4 represents the four sum error information items (sε1...4), and
   ici1...4 represents the four reference disturbance information items (ici1...4).

7. The method as claimed in claim 3 or 4, **characterized** in that the correction information (ici_{opt}) is determined in the course of an iterative search, with the k reference disturbance information items (ici1...4) being established in the course of the iterative search, and the steps (a) to (c) being

repeated until a minimum value of the disturbance-information-specific sum error information (ε_{min}) is determined, and the correction information (ici_{opt}) has been derived from this.

8. The method as claimed in one of claims 3 to 7, **characterized** in that the additionally deliberately disturbed received symbols (es'1...n) are in each case corrected by equalization as a function of frequency-selective transmission characteristics (H(f)) of the transmission medium (FK) before the comparison with the respective closest modulation-specific modulation symbol.

9. The method as claimed in one of claims 3 to 8, **characterized**
   - in that, once steps (a) to (d) have each been carried out for each reference disturbance information item (ici1...4)
   -- (a') the received symbols (es1...n) of the subcarriers (st_{i-b}, st_{i+b}, where b > 1) which are each arranged further away from at least some of the subcarriers (st_i) in the frequency domain are each subjected to disturbances from the reference disturbance information (ici1...4), and the disturbed received symbols are then additively superimposed as deliberate test disturbances ($icix_{-1}$, $icix_{+1}$) on the received symbol (es1...n) of the additionally disturbed subcarrier (st_i), and
   -- steps (b) to (d) are then carried out.

10. The method as claimed in one of claims 2 to 9, **characterized**
   - in that the received symbols (ves'1...n) which have been corrected using the correction information (ici_{opt}) are demodulated,,

- in that errors are identified in the demodulated received symbols (di) using error identification information inserted into the transmitted information, and identified, erroneous received symbols (es'1...n, es''1...n) are corrected,
- in that, when errors are identified, steps (b) to (d) are carried out once again, with the corrected received symbols (es'1...n, es''1...n) being used for determining the correction information (ici_{opt}).

11. The method as claimed in one of the preceding claims,
characterized
in that the multicarrier method is provided by means of an OFDM transmission method - Orthogonal Frequency Division Multiplexing - or by means of a transmission method based on discrete multiple tones - DMT.

12. The method as claimed in one of the preceding claims,
characterized
in that the transmission medium is in the form of a wireless radio channel or a cable-based or wire-based transmission channel.

13. The method as claimed in claim 12,
characterized
in that the information is transmitted via power supply lines.

14. Use of the method according to the invention as claimed in one of the preceding claims,
characterized
- in that the received multicarrier signal (ms) is demodulated,
- in that errors contained in the demodulated multicarrier signal (di) are identified using an error handling routine and are corrected,
- in that the method is carried out in order to deliberately disturb the received multicarrier signal (ms) as a function of the number and correctability of the errors.

15. A receiving arrangement for receiving a multicarrier signal (ms) having a number of

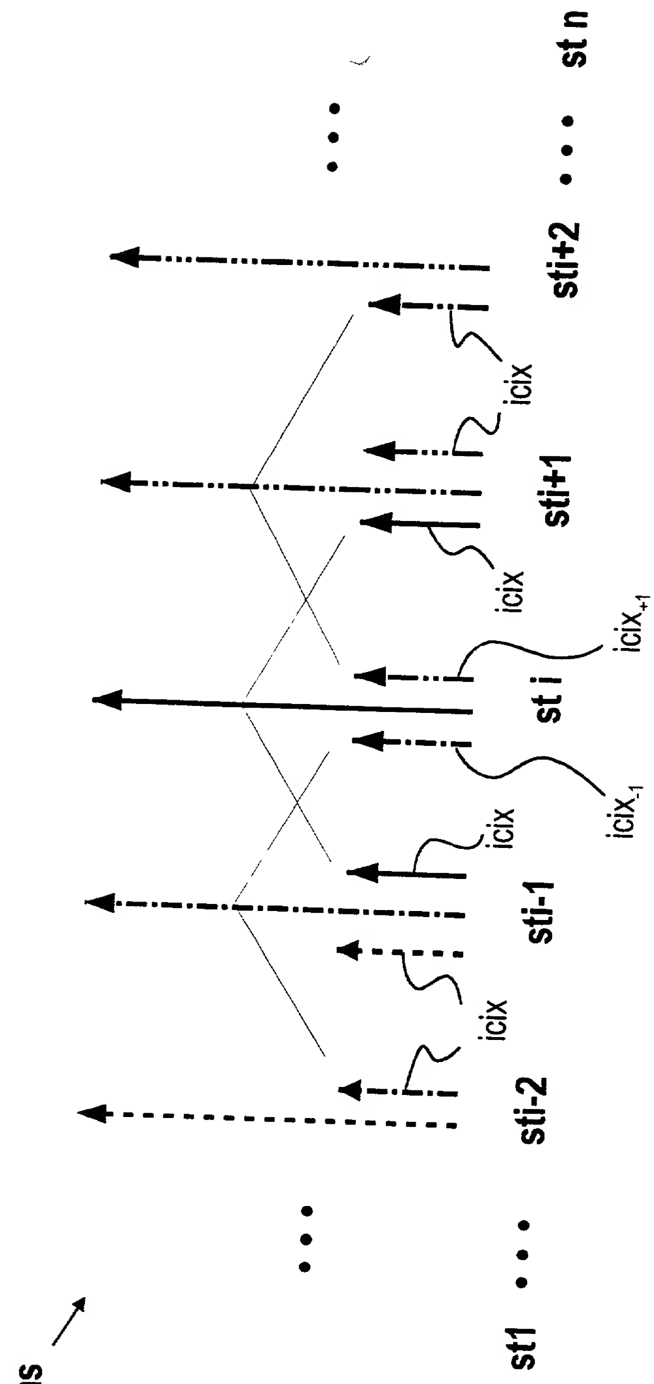
frequency-discrete subcarriers (st1...n) and into which information is inserted which is converted into frequency-discrete modulation symbols by means of a multicarrier method,
with the individual frequency-discrete subcarriers (st1...n) of the multicarrier signal (ms) transmitted via a transmission medium (FK) each being subject to subcarrier-specific disturbances (ici0)

caused by subcarriers (st1...n) arranged adjacent in the frequency domain,

characterized

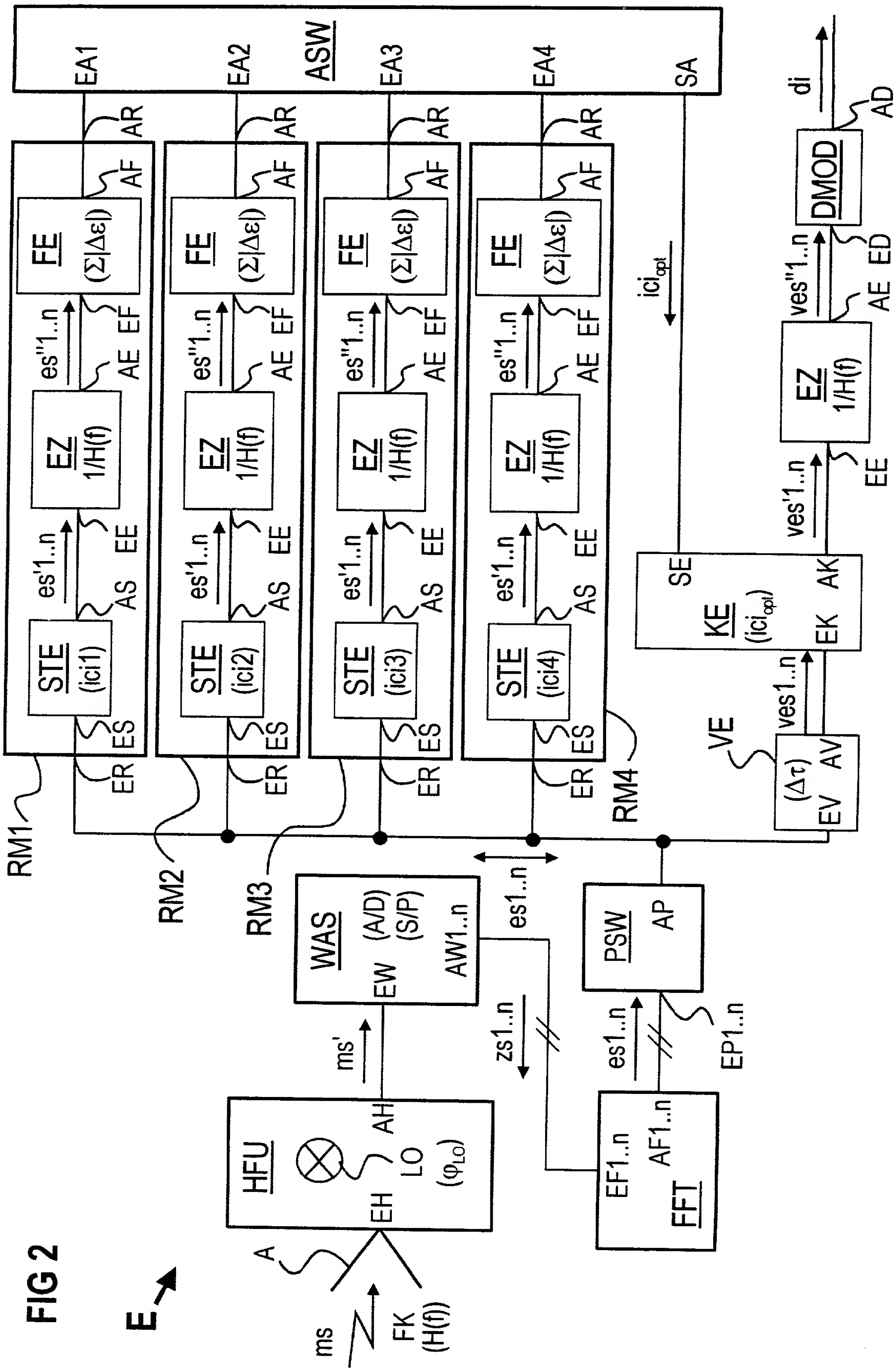
- in that disturbance means (RM1..4) are provided for additional, deliberate disturbance of the received multicarrier signal (ms),
- in that means (ASW) are arranged for deriving correction information (ici_{opt}), which represents the subcarrier-specific disturbances (ici0), from the additionally deliberately disturbed subcarriers (st1...n, es'1...n, es''1...n), and
- in that means (KE) are provided for correction of the frequency-discrete subcarriers (st1...n, ves1...n) as a function of the determined correction information (ici_{opt}).

FIG 1



ms
st1
sti-2
icix
sti-1
icix
$icix_{-1}$
st i
$icix_{+1}$
icix
sti+1
icix
sti+2
st n

FIG 2



E
ms
FK
(H(f))
A
EH
HFU
LO
(φ_{LO})
AH
ms'
EW
WAS
(A/D)
(S/P)
AW1..n
zs1..n
es1..n
EF1..n
AF1..n
FFT
es1..n
EP1..n
PSW
AP
RM1
RM2
RM3
RM4
ER
ES
STE
(ici1)
(ici2)
(ici3)
(ici4)
AS
es'1..n
EE
EZ
1/H(f)
AE
es''1..n
EF
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($\Sigma|\Delta\varepsilon|$)
AF
AR
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EA2
EA3
EA4
ASW
SA
ici_{opt}
SE
KE
(ici_{opt})
EK
AK
VE
($\Delta\tau$)
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AV
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ves''1..n
ED
DMOD
AD
di

10100L" 99LLE60

FIG 3

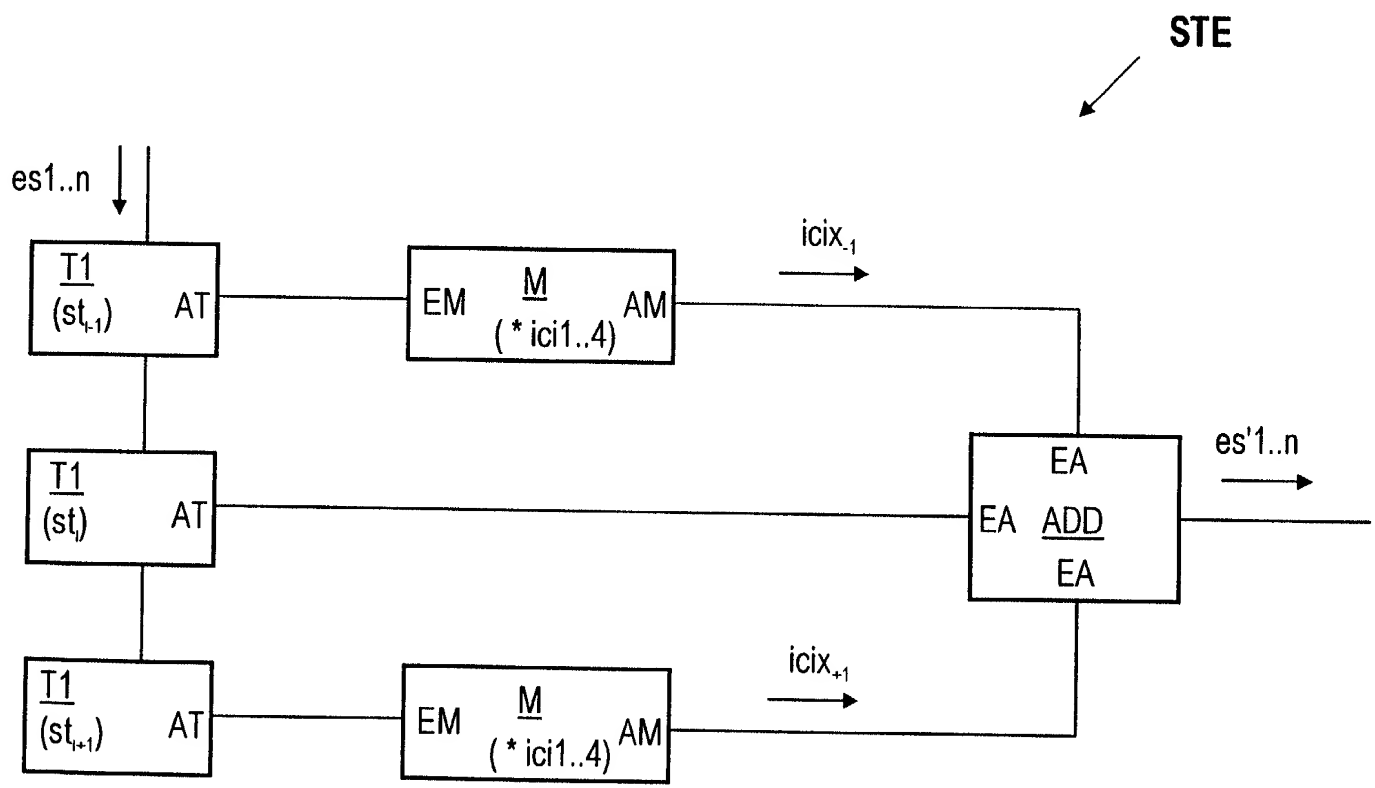
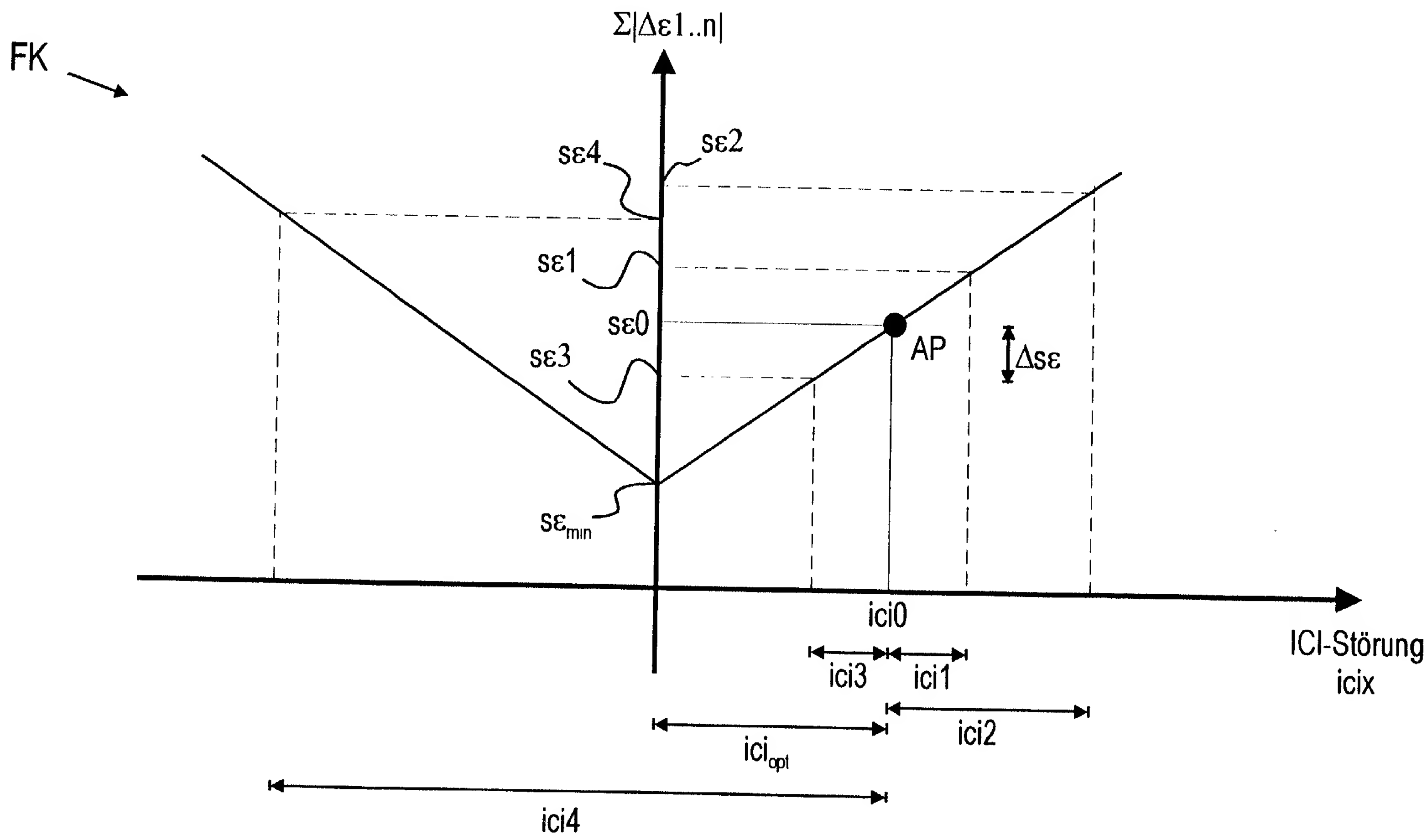


FIG 4



09/937766

Declaration and Power of Attorney For Patent Application
Erklärung Für Patentanmeldungen Mit Vollmacht
German Language Declaration

Als nachstehend benannter Erfinder erkläre ich hiermit an Eides Statt:

As a below named inventor, I hereby declare that:

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My residence, post office address and citizenship are as stated below next to my name,

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I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

Verfahren, Verwendung des Verfahrens und Empfangsordnung zum Empfang von mehrere frequenzdiskrete Subtraeger aufweisenden Multitraegersignalen

Method, use of said method and receiver system for receiving multi-carrier signals presenting several frequency-discrete subcarriers

deren Beschreibung

(zutreffendes ankreuzen)
☐ hier beigefügt ist.
☒ am 06.03.2000 als
PCT internationale Anmeldung
PCT Anmeldungsnummer PCT/DE00/00699
eingereicht wurde und am ________
abgeändert wurde (falls tatsächlich abgeändert).

the specification of which

(check one)
☐ is attached hereto.
☒ was filed on 06.03.2000 as
PCT international application
PCT Application No. PCT/DE00/00699
and was amended on ________
(if applicable)

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I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, §1.56(a).

Ich beanspruche hiermit ausländische Prioritätsvorteile gemäss Abschnitt 35 der Zivilprozessordnung der Vereinigten Staaten, Paragraph 119 aller unten angegebenen Auslandsanmeldungen für ein Patent oder eine Erfindersurkunde, und habe auch alle Auslandsanmeldungen für ein Patent oder eine Erfindersurkunde nachstehend gekennzeichnet, die ein Anmeldedatum haben, das vor dem Anmeldedatum der Anmeldung liegt, für die Priorität beansprucht wird.

I hereby claim foreign priority benefits under Title 35, United States Code, §119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

IDNR: 2590 / V: 99-1.00 / B:Val

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Prior foreign appplications
Priorität beansprucht

Priority Claimed

Number / Nummer	Country / Land	Day Month Year Filed / Tag Monat Jahr eingereicht	Yes / Ja	No / Nein
19914797.3	DE	31.03.1999	☒	☐
			☐	☐
			☐	☐

Ich beanspruche hiermit gemäss Absatz 35 der Zivilprozessordnung der Vereinigten Staaten, Paragraph 120, den Vorzug aller unten aufgeführten Anmeldungen und falls der Gegenstand aus jedem Anspruch dieser Anmeldung nicht in einer früheren amerikanischen Patentanmeldung laut dem ersten Paragraphen des Absatzes 35 der Zivilprozeßordnung der Vereinigten Staaten, Paragraph 122 offenbart ist, erkenne ich gemäss Absatz 37, Bundesgesetzbuch, Paragraph 1.56(a) meine Pflicht zur Offenbarung von Informationen an, die zwischen dem Anmeldedatum der früheren Anmeldung und dem nationalen oder PCT internationalen Anmeldedatum dieser Anmeldung bekannt geworden sind.

I hereby claim the benefit under Title 35. United States Code. §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §122, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, §1.56(a) which occured between the filing date of the prior application and the national or PCT international filing date of this application.

(Application Serial No.) (Anmeldeseriennummer)	(Filing Date D, M, Y) (Anmeldedatum T, M, J)	(Status) (patentiert, anhängig, aufgegeben)	(Status) (patented, pending, abandoned)
PCT/DE00/00699	06.03.2000	anhängig	pending

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German Language Declaration

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	And I hereby appoint

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~~Unterschrift des Erfinders~~ Datum: Wolfgang Zirwas 8.8.01	Inventor's signature Date
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Staatsangehörigkeit: DE	Citizenship: DE
Postanschrift: MITTENWALDER STR.136	Post Office Address: MITTENWALDER STR.136
82194 GROEBENZELL	82194 GROEBENZELL

Voller Name des zweiten Miterfinders (falls zutreffend):	Full name of second joint inventor, if any:
Unterschrift des Erfinders Datum	Second Inventor's signature Date
Wohnsitz ,	Residence ,
Staatsangehörigkeit	Citizenship
Postanschrift	Post Office Address

(Bitte entsprechende Informationen und Unterschriften im Falle von dritten und weiteren Miterfindern angeben).	*(Supply similar information and signature for third and subsequent joint inventors).*